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APPLICATION AND EVALUATION CONSIDERATIONS FOR IN SITU VITRIFICATION TECHNOLOGY: A TREATMENT PROCESS FOR DESTRUCTION AND/OR PERMANENT IMMOBILIZATION OF HAZARDOUS MATERIALS

Geosafe Corporation

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THIS REPORT PROVIDES AN OVERVIEW OF THE IN-SITU VITRIFICATION TECHNOLOGY AND ITS APPLICABILITY TO DIRECT REMEDIATION TREATMENT OF VARIOUS TYPES OF HAZARDOUS WASTES. IT IS DIVIDED INTO THE FOLLOWING SECTIONS:

1. PROCESS AND EQUIPMENT DESCRIPTION
2. APPLICABILITY CONSIDERATIONS - WASTE COMPOSITION, PRESENCE OF WATER, SITE TOPOGRAPHY
3. EVALUATION CRITERIA - PERMANENCE, REDUCTION OF TOXICITY, COST, IMPLEMENTABILITY
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Geosafe Corporation provides in situ vitrification (ISV) remediation services to public and private sector clients. Geosafe also provides the following ISV-related services: treatability testing; application engineering support of remedial design, permitting and ARARs compliance documentation; and post-operational delisting and sampling/monitoring support.

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APPLICATION AND EVALUATION CONSIDERATIONS FOR IN SITU VITRIFICATION TECHNOLOGY: A TREATMENT PROCESS FOR DESTRUCTION AND/OR IMMOBILIZATION OF HAZARDOUS MATERIALS

GEOSAFE CORPORATION
APRIL 1989

I. INTRODUCTION

In Situ Vitrification (ISV) is a unique technology that may be applied to the direct treatment or in situ containment of hazardous materials. This document focuses on direct treatment applications; its purposes are to: 1) provide a guide for considering various types of ISV treatment applications, and 2) provide information regarding how the ISV process satisfies various evaluation criteria for alternative technology selection studies.

ISV technology has been under development and testing by the Pacific Northwest Laboratories Division of Battelle Memorial Institute (Battelle) since 1980. ISV was originally developed for possible application on soils previously contaminated with radioactive transuranic materials (e.g., Pu, Am, U), related refuse (e.g., wood, plastic, rubber, metal, cloth, cleaning chemicals, sealed containers), and related process chemicals (e.g., NO_3, SO_4, F, CCl_4, TBP). This original work, in a previously unexplored area of technology, resulted in basic and broad patent protection.

During the development work, potential application of the technology to the hazardous chemicals of concern under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) and the Resource Conservation and Recovery Act (RCRA) became obvious, and additional development work was directed toward such wastes. The process system has been developed and demonstrated through large-scale; wastes treated include a variety of hazardous chemical, radioactive, and mixed (hazardous and radioactive) wastes. Development and testing on various hazardous materials has enabled the deployment of ISV for commercial application.

The primary sponsor for the development and test work has been the U.S. Department of Energy (DOE); other sponsors include the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DOD), the Electric Power Research Institute (EPRI), Battelle, Geosafe, and numerous other private companies. Battelle has obtained exclusive rights to application of the technology in the field of hazardous waste remediation. Battelle, in turn, has exclusively sublicensed Geosafe Corporation (Geosafe) for the commercial deployment of the technology.

This document provides an overview of the ISV technology and its applicability to direct remediation treatment of various types of hazardous wastes. The document is organized into sections that first describe the technology and technical considerations pertinent to its application. The technology is then discussed relative to the evaluation criteria that are typically addressed during feasibility studies of alternative site remediation technologies. Lastly, a qualitative comparison of ISV to other major alternative technologies is presented. The possible use of ISV as a hazardous waste containment technology (containment as opposed to direct treatment) is discussed in Appendix E.

A large amount of data and application experience has been obtained from the greater than 70 ISV tests that have been performed at various scales since 1980. It is not the purpose of this paper to report that data and experience, but rather to present the general applicability-related conclusions that have been derived from it. The reader is referred to Geosafe for more detail on specific prior work.

II. PROCESS AND EQUIPMENT DESCRIPTION

ISV is a process that electrically melts inorganic materials (e.g., soil) for the purpose of thermochemically treating free and/or containerized contaminants present within the treatment volume. Most ISV applications involve melting of natural soils; however, other naturally occurring or process residual inorganics (e.g., sludge, tailings, sediments), or process chemicals may be utilized. For purposes of simplification, primarily soil applications are discussed hereafter in this document. It should be noted that when other inorganics are utilized in the ISV process, some variation of application detail may be necessary compared to soil applications. Utilizing soil, the process simultaneously destroys and/or removes organic contaminants while chemically incorporating (immobilizing) inorganic contaminants into a chemically inert, stable glass and crystalline residual product.

Figure 1 illustrates sequential stages of ISV processing. First an array (usually square) of four electrodes is placed to the

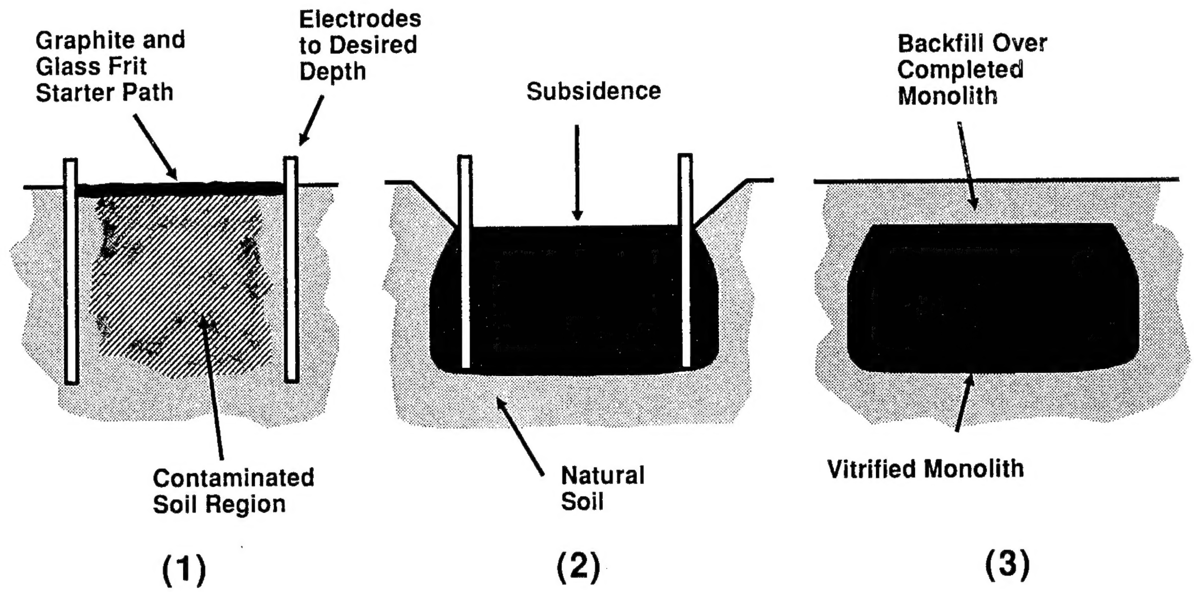


FIGURE 1. Stages of ISV Processing

desired treatment depth in the volume to be treated. Because soil typically does not have sufficient electrical conductivity to allow initiation of the process, a conductive mixture of graphite and glass frit is placed on the surface between the electrodes to serve as an initial conductive (starter) path. As electric potential is applied between the electrodes, current flows through the starter path, heating it and the adjacent soil to temperatures above 1,600°C, which is well above typical soil fusion temperatures. Upon melting, typical soils become quite electrically conductive; thus the molten mass becomes the primary conductor and heat transfer medium allowing the process to continue beyond startup.

Continued application of electric energy causes the molten volume to grow downward and outward encompassing the desired treatment volume. Individual settings (i.e., the melt involved with a single placement of electrodes) may grow to encompass a total melt mass of up to 1,000 tons and a maximum width of about 30 ft. Single setting depths as great as 30 ft are considered possible with the existing large-scale ISV equipment (Appendix B addresses deeper depths). Several methods, utilizing geophysical, optical, and thermal principals, may be used to determine the physical extent of melting for control purposes. Figure 2 illustrates how adjacent settings are positioned to fuse to each other and to completely process the desired volume at a site.

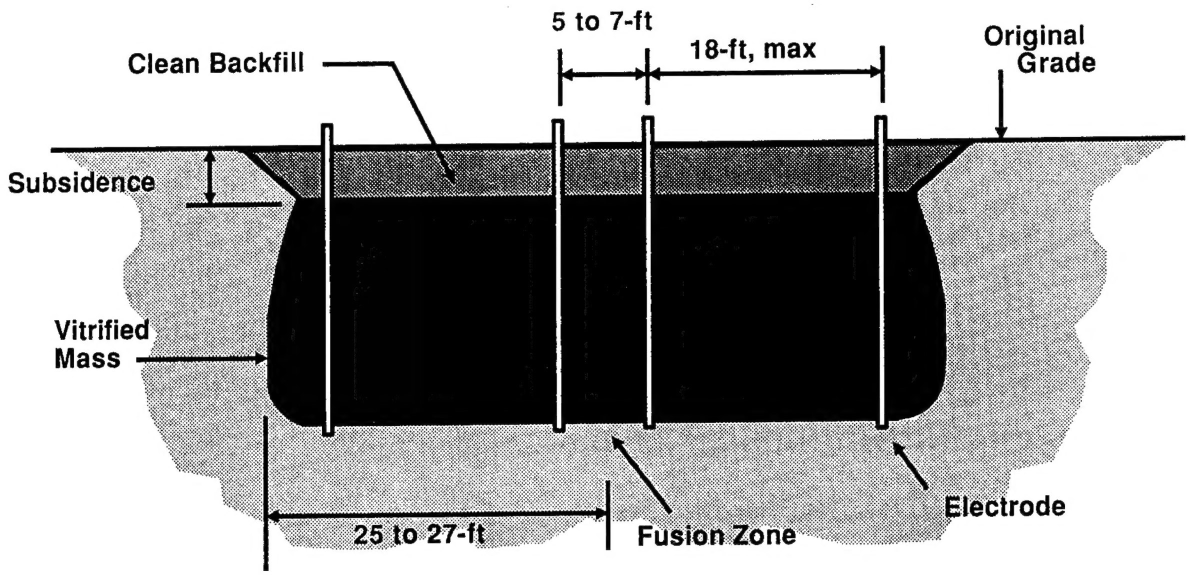


FIGURE 2. Relationship of Adjacent Settings

The molten soil mass is typically in the 1,600 to 2,000°C temperature range; specific temperatures are dependent on the overall chemistry of the melt. Within the melt, a vigorous, chemically reducing environment is typical. Because soil typically has low thermal conductivity, a very steep thermal gradient (i.e., 150-250°C/in) precedes the advancing melt surfaces. Typically, the 100°C isotherm is less than 1 ft away from the molten mass itself.

The large-scale ISV system melts soil at a rate of 4 to 6 tons/hr. Accordingly, the rate of melt advance is in the 1 to 2 in/hr range. As the thermal gradient advances on solid or liquid organic materials, they first vaporize and then pyrolyze (i.e., decompose in the absence of oxygen) into elemental components. Organic pyrolysis products are typically gaseous; these gases move slowly (because of the high viscosity of the molten material) through the melt toward the upper melt surface. Some of these gases may dissolve into the molten mass; the remainder move to the surface where those that are combustible combust in the presence of air. Pyrolysis and combustion products are collected in an off-gas collection hood and are subsequently treated to ensure process air emissions meet regulatory requirements. Because of the high temperature of the melt, no residual organic contamination remains in its original compound form within the vitrified product.

The behavior of inorganic materials, upon exposure to the advancing thermal gradient, is similar to that of the organics. Inorganic compounds may thermally decompose or otherwise enter into

reactions with the melt. Nitrates and sulphates, for example, yield gaseous decomposition products (e.g., N_2, SO_2, O_2) which may dissolve into the melt or may evolve through it and be collected in the off-gas collection hood. Typically, the elements of the inorganic compounds originally present are incorporated into the vitrified residual. Additional detail regarding the disposition of hazardous contaminants during ISV processing is provided in Appendix A.

Since the void volume present in particulate materials (e.g., 20-40% for typical soils) is removed during ISV processing, a corresponding volume reduction occurs. Also, since some of the materials (e.g., humus, organic contaminants, limestone) present in the soil are removed as gases and vapors during processing, further volume reduction occurs. The volume reduction creates a subsidence volume above the melt and an angle of repose in the soil adjacent to the melt.

As the melt grows in size, its electrical resistance decreases, making it necessary to periodically adjust the ratio between the voltage and the current to maintain operation at the desired power level. When the power is shut off, the extent of melting is limited to the point achieved at that moment, and the melt starts to cool. Within a few hours, gaseous emissions from the melt cease. After that time has passed, the off-gas hood may be removed and the subsidence volume filled to the desired depth with clean backfill. No attempts are made to force cool the melt; slow cooling results in a vitreous (amorphous) and microcrystalline structure which provides excellent structural properties. The vitrified product is monolithic in nature (i.e, a single massive structure); and assuming contiguous (i.e., immediately adjacent) settings at a site, a single large monolith will be produced, as shown in Figure 2.

The process utilizes an equipment system as illustrated in simplified form on Figure 3. Electric power is usually taken from a utility distribution system at typical transmission voltages of 12,500 or 13,800 volts; alternatively the power may be generated onsite by a diesel generator. The 3-phase power is supplied to a special multiple-tap transformer (Scott Tee) that converts the power to 2-phase and transforms it to the voltage levels needed throughout the processing. The electrical supply system utilizes an isolated ground circuit which provides appropriate operational safety.

Electric power is supplied to the array of electrodes through flexible conductors. The electrodes are placed through a process utilizing casings that are vibrated or driven into place, followed by vibratory extraction after placement of the electrodes within the casings. Electrodes are typically left in place while the residual monolith cools; they may then be removed for recycling or partial reuse. The electrode locations may also be

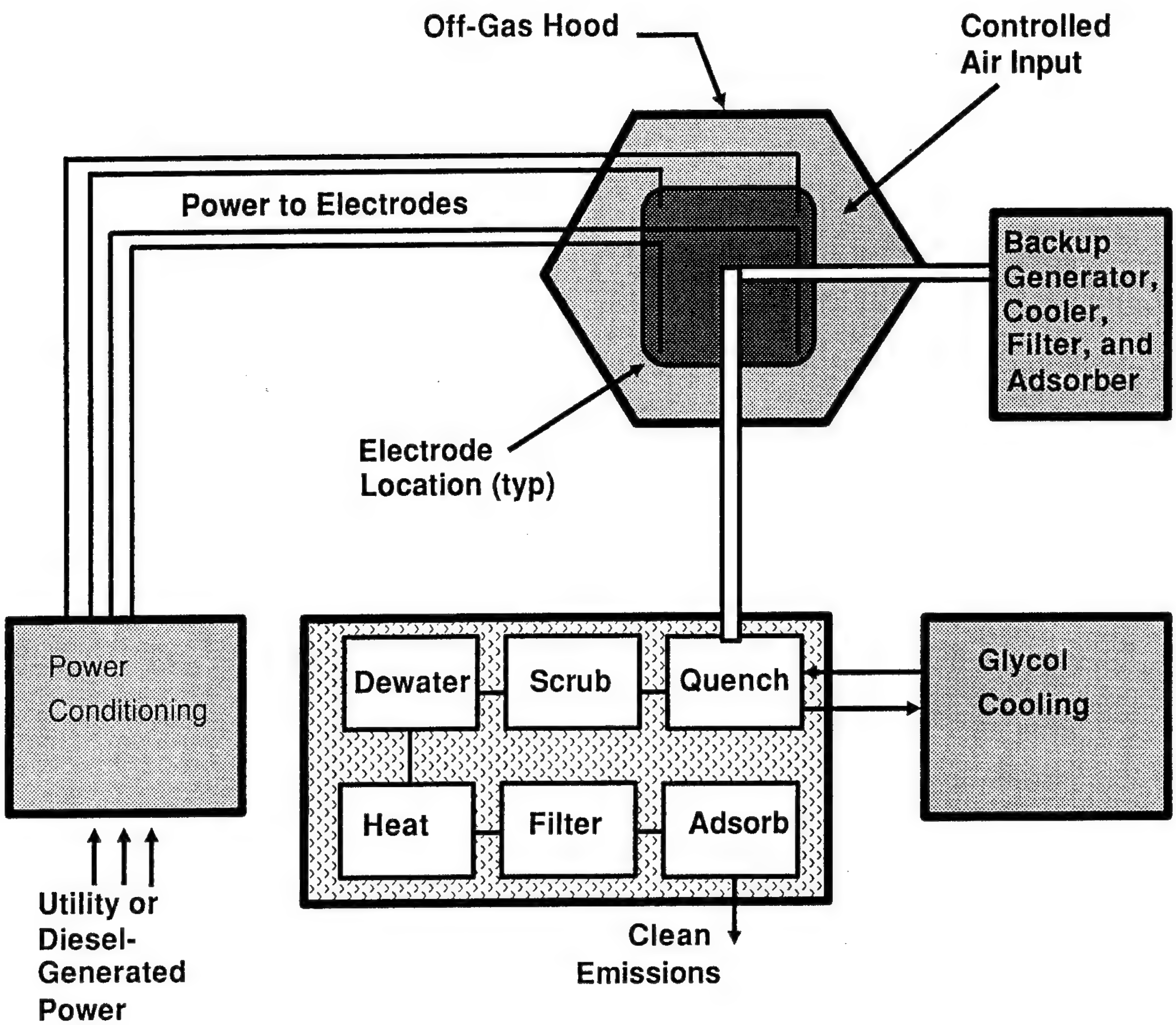


FIGURE 3. ISV Equipment System

utilized as a penetration through the monolith for access to groundwater, for example.

The maximum spacing between electrodes in the large-scale equipment system is about 18 ft, which allows formation of a maximum melt width of about 28 ft. The processing area is covered by a octagonal-shaped (nearly round) off-gas collection hood with a maximum dimension across the flats of 55 ft. The large distance between the edge of the hood and the edge of the melt ensures

off-gas containment even under worst case angle of repose (from subsidence) conditions.

Flow of air through the hood is controlled to maintain a negative pressure (0.5 to 1.0 in H_2O). An ample supply of air provides excess oxygen for combustion of pyrolysis products and organic vapors, if any. The off-gases, combustion products and air are drawn from the hood (by induced draft blower) into the off-gas treatment system which utilizes the following unit processes to ensure compliant air emissions: 1) quenching, 2) pH controlled scrubbing, 3) dewatering (mist elimination), 4) heating (temperature and dewpoint control), 5) particulate filtration, and 6) activated carbon adsorption. A self-contained glycol cooling system is utilized to cool the quenching/scrubbing solution; this avoids the need for a constant onsite water supply. The amount of moisture present in the exhaust air stream is controlled to accommodate the moisture that is removed from the treatment volume during processing.

Typically, the volume of gases evolving from the melt represent less than 1 vol% of the total volume of air processed by the off-gas treatment system. Also typically, there is very little, if any, hazardous material that evolves from the melt during processing. In addition to pyrolysis and combustion products, some amount of particulate may be present in the off-gas. Substantially all of the off-gas contaminants are removed from the off-gas stream at the quenching and scrubbing stages. The filters and carbon adsorption columns are utilized as secondary stages (backup) to ensure safe air emissions. After processing for a time, the scrubber solution, filters, and activated carbon may contain sufficient contaminants to warrant treatment or disposal themselves. Typical treatment includes passing the scrubber water through diatomaceous earth (filter aid) and activated carbon, followed by reuse of the water or discharge to a sanitary sewer, and placement of the activated carbon and filters in a subsequent ISV setting for reprocessing. In this way, the destruction/chemical incorporation of contaminants collected in the off-gas treatment system is maximized, and the only secondary waste resulting from the ISV processing is that contained in the off-gas treatment system after the last setting at a site.

In addition to the primary off-gas treatment system, the ISV process system employs a backup off-gas treatment system for use in the event of power failure. The backup system employs a diesel-powered generator, blower, mist cooler, filter and activated carbon column. The backup system is capable of removing and treating off-gases for the period of time that a melt may release off-gases during a power outage or during the initial cooling time at completion of a setting.

The overall ISV process is monitored and controlled by a distributed microprocessor system. The process equipment system util-

izes a large number of safety methods and devices to ensure safety of operations. The process is monitored and controlled by two qualified operators at all times. The process operates around-the-clock with about 16-hrs of downtime between settings. Support personnel perform advance preparatory work (e.g., electrode placement) during operation of the system to minimize the movement-associated downtime.

III. APPLICABILITY CONSIDERATIONS

A. ISV System Physical Capabilities

The ISV process and equipment system possess the general capabilities presented in Table 1. For typical applications, the large-scale ISV equipment is capable of processing: 1) a mass in the range of 800 to 1,000 tons of soil in a single setting, 2) a maximum melt area of about 900 sq-ft (e.g., 30-ft by 30-ft), and 3) a maximum depth of 30-ft. For most soils, it is not possible to reach all three of these limits at the same time; that is, the maximum tonnage would occur in a 30-ft by 30-ft setting before reaching the 30-ft depth. Thus, depth and setting areal dimensions are trade-offs that must be considered during remedial design.

TABLE 1. General ISV System Physical Capabilities

Surface Area Dimensions	10 ft x 10 ft (minimum) 30 ft x 30 ft (maximum)
Depth	5 to 7 ft (economic minimum) 30 ft (estimated single setting maximum; see Appendix B for deeper depths)
Processing Rate	4 to 6 ton/hr
Melt Mass	800 to 1,000 ton (maximum)
Melt Temperature	1,600 to 2,000°C (soils)
Power Level	1.9 Mw/phase (3.8 Mw total)
Electrical Consumption	0.4 to 0.5 kwh/lb (soil)

B. Alternative Waste Arrangements for Processing

The soil/waste to be processed by ISV may be arranged for processing in several ways; selection among alternatives is based on consideration of: 1) the physical state of the material (e.g., solid, liquid, slurry, sludge), 2) the location of the material (e.g., in soil, in containers, in an impoundment, under or near structures, in the water table), 3) expected response of the material to ISV processing (e.g., volume reduction, angle of repose, expected gas/vapor volumes), and 4) the physical capabilities of the ISV processing equipment (e.g., maximum width and depth of settings).

Eight possible soil/waste arrangements are illustrated and discussed in Appendix B; for purposes of brief definition, they are listed below. Combinations of the basic arrangements may also be possible.

1) <u>In Situ</u> - treatment of contaminated materials in their present location (e.g., landfills and impoundments).

2) <u>Modified In Situ</u> - treatment of landfills or impoundments with some rearrangement of berm materials or filling to berm level with additional material.

3) <u>Below-Grade Staging</u> - staging of contaminated materials within a below-grade trench.

4) <u>Above-Grade Staging</u> - staging materials fully or partially above-grade; a variation of 3).

5) <u>Tank/Container Settings</u> - processing of tanks or other containers previously filled with soil and located or staged within soil.

6) <u>Stacked Settings</u> - formation of multiple settings one on top of the other; applicable to in situ and/or staged contamination at depths greater than the single setting depth capability (>30 ft).

7) <u>Process-Container Repetitive Settings</u> - performance of repetitive settings, one on top of the other, within a process container; applicable to very high volume reduction materials; a variation of 6).

8) <u>Continuous Feed Settings</u> - processing of a large volume of material in a single setting; applicable to high volume reduction materials.

C. Waste Composition and Properties

For purposes of this discussion, the universe of wastes is categorized into hazardous, radioactive, and mixed (hazardous plus radioactive) types as indicated in Figure 4. The overlapping array of squares in the figure illustrate the possible combinations of waste types. The ISV process is applicable to all types of waste, including mixtures of types, within certain application limits which are discussed in this and other sections below. The ISV process simultaneously performs its work on the various waste types present in a treatment volume. This simultaneous capability is considered an important advantage of ISV relative to other technologies. With mixtures of waste types, it is usually necessary to utilize more than one non-ISV technology, in sequential fashion, to accomplish a total remediation.

As discussed in Section II above, and Appendix A, the ISV process simultaneously destroys, removes, and immobilizes hazardous contaminants by exposure to the high temperature melt. Contaminant decomposition or pyrolysis products either enter into the melt and resulting residual product or they evolve to the surface, where they are collected in the off-gas hood and are subsequently treated by the off-gas treatment system. For consideration of processing by ISV then, particular contaminants must be evaluated for acceptability in the following areas:

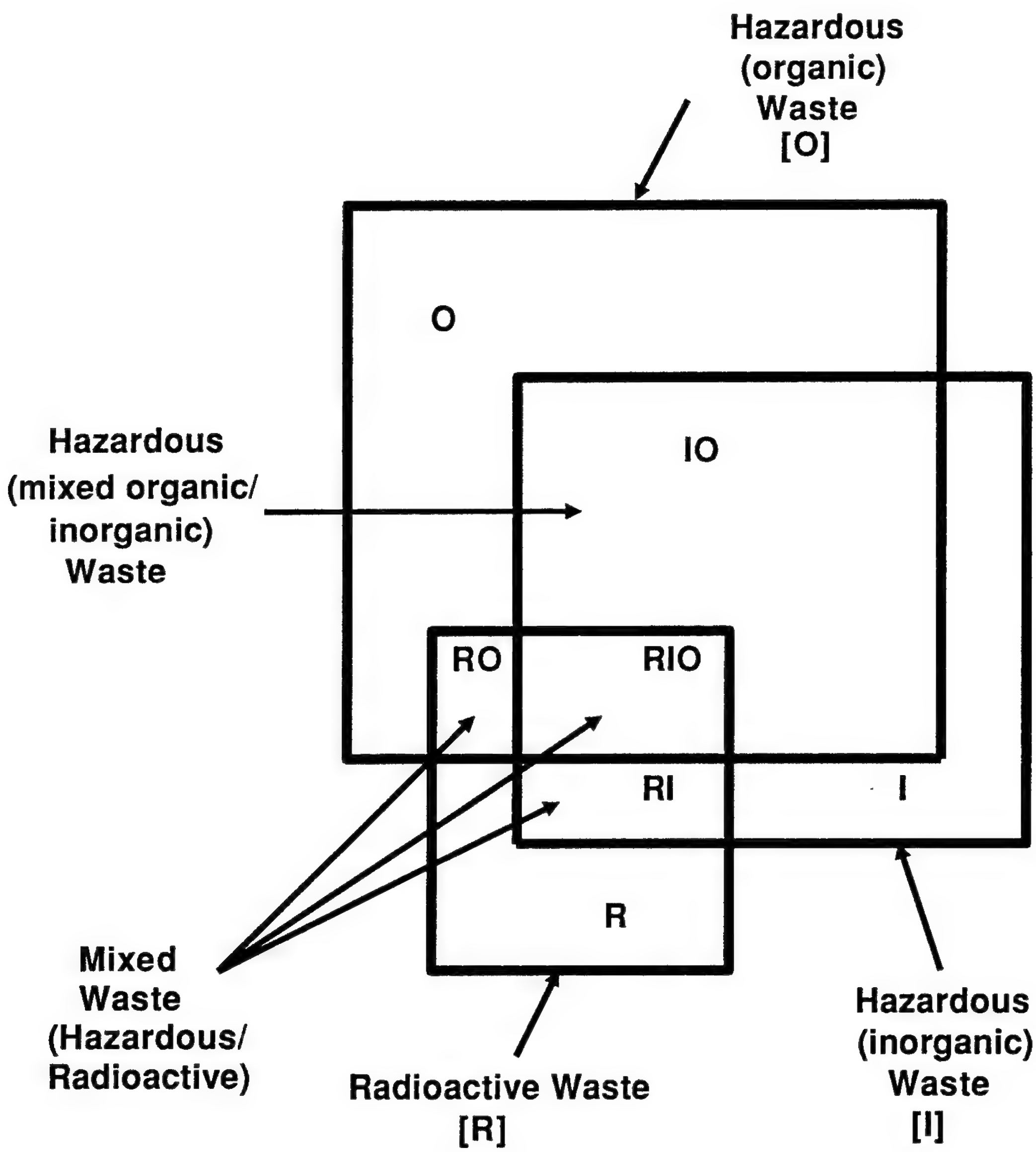
1) Expected response to processing (i.e., destruction, removal, immobilization)

2) Ability of the ISV equipment system to accommodate the expected response (i.e., off-gas volumes, thermal loading, subsidence)

3) Expected performance of the residual product, if applicable

4) Ability of the process to meet regulatory requirements (e.g., cleanup levels).

As a broad generalization, nearly all (typically 99.9 to 99.995 wt%) of the organic contaminants present in the treatment volume may be expected to undergo destruction by pyrolysis during a single setting of the ISV process. The remainder will experience removal and capture in the off-gas treatment system. Hazardous materials captured in the off-gas system are periodically recycled back to a subsequent ISV setting where additional destruction/immobilization occurs. In this way, substantially all of the contaminants at a site are destroyed/removed/immobilized by the ISV treatment. It is possible for a very small portion (trace) to remain as an untreated residual in the soil adjacent to the residual monolith. In such instances, the specific concentrations are well below regulatory action (cleanup)



<u>FIGURE 4</u>. Possible Combinations of Hazardous, Radioactive and Mixed Wastes

levels, and are so low as to not adversely impact overall destruction and removal efficiencies. Specific performance depends on the properties of individual organics. These comments apply to organic-only wastes and to the organic portion of

organic/inorganic/radioactive waste mixtures (types O, IO, RO, RIO on Figure 4).

In similar fashion, nearly all inorganic contaminants in the treatment volume, with the exception of compounds that decompose into gaseous products, will be chemically incorporated into the melt and become part of the residual monolith produced. As with organics, it is possible for some inorganics (e.g., Hg) to evolve from the melt in the vapor state and to be captured in the off-gas treatment system. Such captured materials may be subject to recycling to a subsequent ISV setting to maximize the degree of incorporation/immobilization. Typically the percentage evolved is quite small (e.g., <0.1%). The degree of retention of inorganic vapors within the melt is a function of elemental vapor pressure, solubility in the glass, and depth of melt. These comments apply to inorganic-only wastes and to the inorganic portion of inorganic/organic/radioactive waste mixtures (types I, IO, RIO on Figure 4).

The above comments also apply to most radioactive materials which, in addition to being radioactive, behave chemically as heavy metals (the radioactive portion of types R, RO, RIO, RI on Figure 4). Since radioactive elements cannot be destroyed, prudent waste management requires immobilization of radioactive wastes to maximize safety during environmental exposure. Whereas most radioactive materials of interest are solid inorganics, the exception of radon-222, which is a gas, is noteworthy relative to ISV application. During ISV, the precursor to radon-222, radium-226, is immobilized by chemical incorporation in the ISV residual product. When the radium-226 decays to radon-222 within the monolith, the radon gas is contained within the vitrified product until such time (< 4 days) that it decays back to a solid form. This capability is a significant advantage of the ISV process for remediation of radon-producing wastes.

The ability of the ISV equipment system to accommodate the response of contaminants to processing relates primarily to the off-gas collection and treatment system. The system has specific volumetric throughput and heat removal capabilities. Limits must be placed on the concentration of combustible organics and other materials that may become gaseous during processing to ensure an adequate safety factor relative to these capabilities.

If contaminant immobilization is a desired objective of a remediation project, then it is necessary to analyze the contaminants in conjunction with the soil matrix to determine if a suitable residual will be produced for immobilization purposes. In such cases it is necessary to evaluate: 1) the concentration of specific inorganics relative to their solubility level in glass, 2) the expected retention percentage in the melt, and 3) expected leaching characteristics from the residual product.

As a general rule, organic contaminants at concentrations in the 5 to 10 wt% range, and inorganics at concentrations in the 5 to 15 wt% range, in soil, may be acceptable for ISV treatment. However, there are waste-specific exceptions to this broad generalization. Therefore, consideration of ISV as an alternative should include having Geosafe perform an applicability evaluation for the specific site based on site characterization information including contaminant chemical types and concentrations. In such evaluations, Geosafe considers the specific contaminants relative to: 1) the soil matrix involved, 2) prior experience with the specific and related contaminants, 3) possible modifications or additions to the waste-matrix combination that may affect its processibility, and 4) the overall objectives of the project, including pertinent regulatory standards.

The ISV test data base includes experience with a large number of waste types. The waste materials that have been involved in previous ISV tests, at significant concentration levels, are listed in Table 2. The reader is referred to Geosafe for further detail regarding specific waste materials.

TABLE 2. Waste Materials That Have Been Processed in ISV Tests

Heavy Metals	Liquid Organics	Solid Organics	Radioactive Materials
Lead	PCBs	Wood	Plutonium
Nickel	Dioxin	Buna Rubber	Amerecium
Cadmium	Trichlor-ethylene	PVC	Radium
Arsenic	Carbon Tetra-chloride	Polyethylene	Uranium
Barium	Dichloro-benzene	Neoprene	Radon
Zinc	Benzene	Ion Exchange Resin	Cesium
Mercury	Methylene Chloride	Teflon	Ruthenium
Copper	Toluene	Paper	Cobalt
Aluminum	Ethylene Glycol	Cotton	Strontium
Iron	Methyl ethyl ketone	Polypropylene	
		DDT, DDD, DDE	

D. Soil Composition and Properties

ISV processing requires sufficient glass forming materials (e.g., Si and Al oxides) present with the waste materials to form and support a high temperature melt. As noted in the process description above, it is the exposure to the melt that causes the

contaminant materials to break down, evolve as gases or vapors, or otherwise react with and chemically participate in the residual ISV product. Inherent in the ability to form a melt, is the necessity for sufficient monovalent alkali cations (e.g., Na, K) to provide the degree of electrical conductivity needed for the process to efficiently operate. This last requirement is one that can be satisfied by adding fluxing materials (e.g., $NaCO_3$) to the base inorganic material. It has been found that the above conditions can be met by most naturally occurring soils, sediments, and tailings, and by many process sludges.

The ISV process has been tested on 18 different soil types taken from government and private sites throughout the United States and Canada. Most soils were found to be capable of supporting a melt and of producing an excellent residual product without modification. In some instances, the need for additives to lower melt temperature or to enhance electrical conductivity, was identified.

Differences in soil types (e.g., clay versus sand) relate primarily to particle size and shape differences, and mineral types resulting from weathering of rocks. These differences affect important soils properties such as permeability and density, but they do not generally affect overall chemical composition and processibility by ISV.

In many applications the soil profile may be stratified and present non-uniform characteristics for ISV processing. Such variables can have an effect on process performance such as process rate and dimensions of the melt produced. Such stratification must be defined prior to application so that it may be factored into remedial design.

In order to evaluate the acceptability of a particular inorganic mixture containing contaminants, Geosafe requires a chemical definition of the inorganic matrix material. Such information, which is typically acquired during RI/FS activities, allows an initial estimation of melt potential and residual product quality. Additional specific properties tests may be required as part of treatability testing to support formal quotation of remediation projects. Geosafe performs treatability tests in response to SARA requirements; treatability testing is discussed further in Section IV.D.

E. Presence of Water

The ISV process is capable of processing fully saturated soils. In doing so, the process heats the inorganic matrix materials to 100°C at which temperature water is removed by vaporization. It takes about as much electric energy to remove 1 lb of water as it does to melt 1 lb of soil. Therefore, it is in the client's best

interest to maintain the treatment volume in as dry a condition as possible prior to ISV treatment.

ISV may be used to treat contaminants existing within an aquifer under the following conditions: 1) utilization of some means to lower the water table (e.g., pumping down or slurry wall) below the treatment volume (see Figures 5 and 6), 2) removal of the material from the water table followed by staging above the water table for processing (see Figures B-3 and B-4 of Appendix B), or 3) processing directly into the water table, assuming the recharge rate is slow enough to allow it.

Several variables must be evaluated to determine if vitrification into the water table is feasible, including: hydraulic conductivity, hydraulic gradient, depth to groundwater from the surface, and the maximum desired depth of vitrification. These variables are used to calculate the amount of water which must be removed during ISV processing. Each site requires specific evaluation; processing below the water table is generally economically feasible if soil permeability is $< 10^{-4}$ cm/sec.

Water present in the treatment volume is removed by vaporization and processed by the off-gas treatment system. That system controls the moisture content (i.e., humidity) of the final air emissions to maintain a desired level of water in the scrubber solution tank. The movement of water vapor through and around the melt may be instrumental in transporting certain hazardous contaminants (e.g., volatile organics) to and through the melt during processing. In order to evaluate the impact of water content on applicability of ISV for specific projects, it is necessary for Geosafe to be provided information on expected moisture content, matrix permeability, and recharge rates.

F. Presence of Inclusions

The ISV process can accommodate significant quantities of inclusions in the treatment volume. Inclusions are defined as highly concentrated contaminant layers, void volumes, containers, metal scrap, general refuse, demolition debris, rock, or other non-homogeneous materials or conditions within the waste volume. Most inclusions, with the exception of very high melting point ceramics, are treated in the same manner as the hazardous organic and inorganic contaminants during ISV. It is necessary to evaluate the size, concentration and chemical composition of such inclusions during applicability analyses.

Some inclusions such as void volumes, containers, and solid combustible refuse (e.g., wood) represent gas-generation sites which must be evaluated relative to off-gas system volumetric and heat removal capacity. Other inclusions, such as metal and

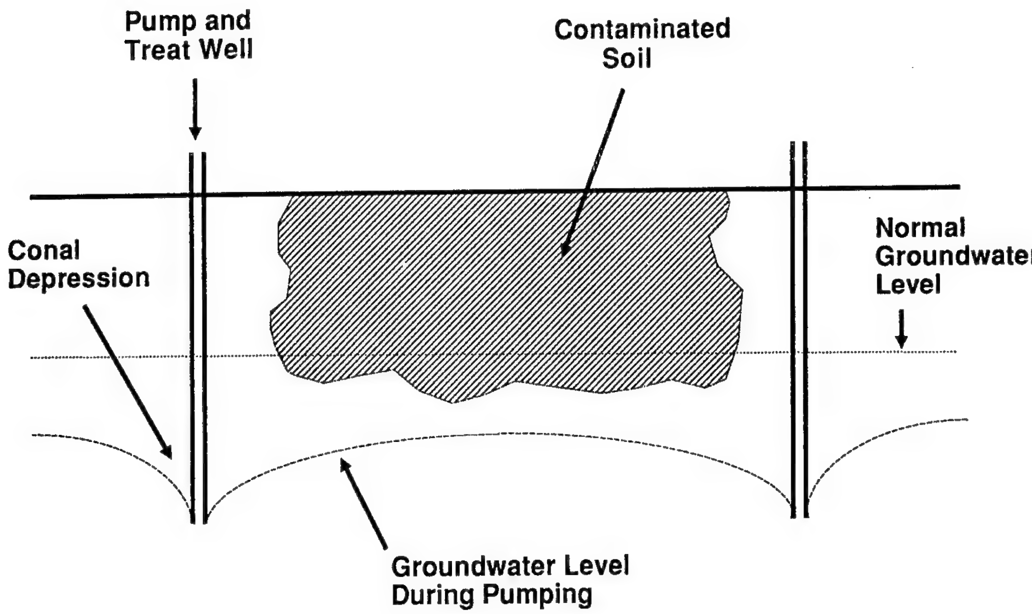


FIGURE 5. Use of Conal Depression to Lower Water Table Under Volume to be Treated

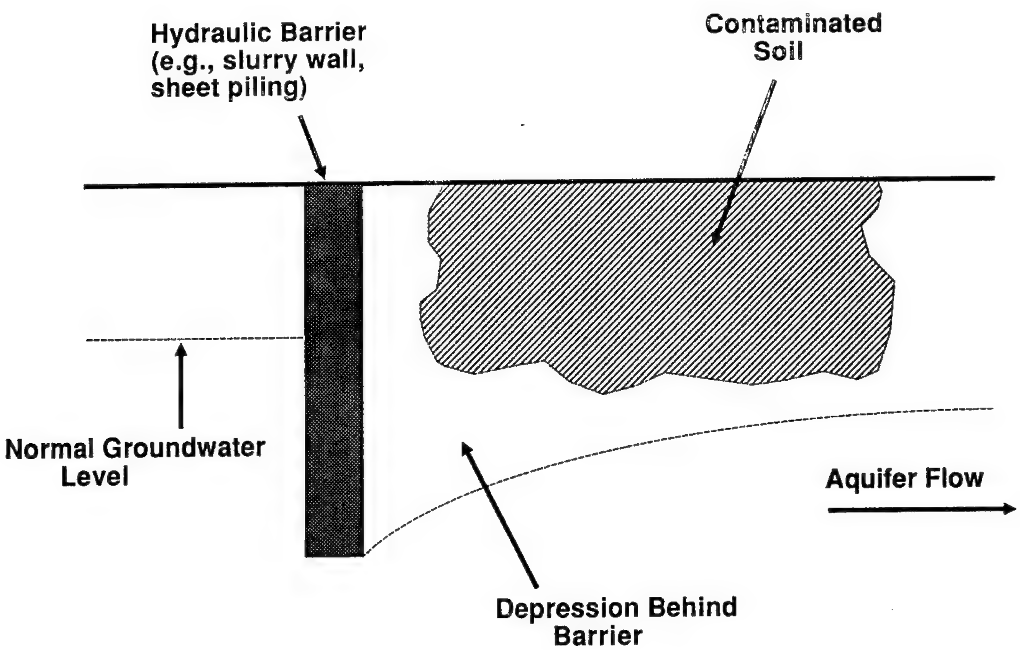


FIGURE 6. Use of a Barrier Wall to Lower Water Table Under Volume to be Treated

inorganic debris must be evaluated regarding their participation in the melt and residual product.

Figure 7 presents general guidance for several types of inclusions. For the special case of buried tanks or other structures possessing large amounts of void volume, the possibility exists of processing such items after first filling them with soil (see Figure B-5 in Appendix B). The process may be utilized to treat metal, plastic, vitrified clay, concrete, asphalt and related construction materials under a variety of conditions. For the special case where underground structures may be the subject of treatment by ISV (e.g., destruction of a failed pipeline containing hazardous materials), such structures must be evaluated as inclusions in the treatment volume. For the special case of drums, it is noted that the metal present in a full setting of stacked drums contributes only 1 to 1-1/2 wt% metal to a setting; this is well below typical metal solubility limits in molten soil. For the special case of high melting point ceramics (e.g., high silica rock) it is possible that such materials may not be melted during ISV processing but rather will be encapsulated by the vitrified mass. The levels specified in the Figure 7 are not hard application limits; rather, the reader should contact Geosafe for specific analysis if the limits are approached or exceeded.

G. Required Cleanup Levels

The ISV process will exceed EPA requirements for 4-9s DRE (i.e., 99.99% destruction and/or removal from treatment volume) for hazardous organics, and 6-9s DRE for PCBs and dioxin, under appropriate application conditions. Similarly, for hazardous inorganics, the ISV residual product will meet EPA's Extraction Procedure Toxicity Test (EP-Tox) and Toxic Characteristics Leaching Procedure (TCLP) leach testing criteria. Performance on specific wastes will vary depending on site- and waste-specific details. The regulatory cleanup requirements for a remediation project on unit volume and site-wide-average bases must be known in order to properly evaluate the potential of the ISV process for specific applications. Geosafe typically requires treatability testing on actual waste samples prior to large-scale remediation operations to verify that the process is capable of satisfying cleanup requirements.

H. Site Topography

The ISV process equipment may accommodate some variations in site topography without special preparation. A level area is required for placement of the equipment trailers. The off-gas collection hood has a flexible skirt at the ground-hood interface that is capable of accepting ±6 inch variations in the soil surface. The

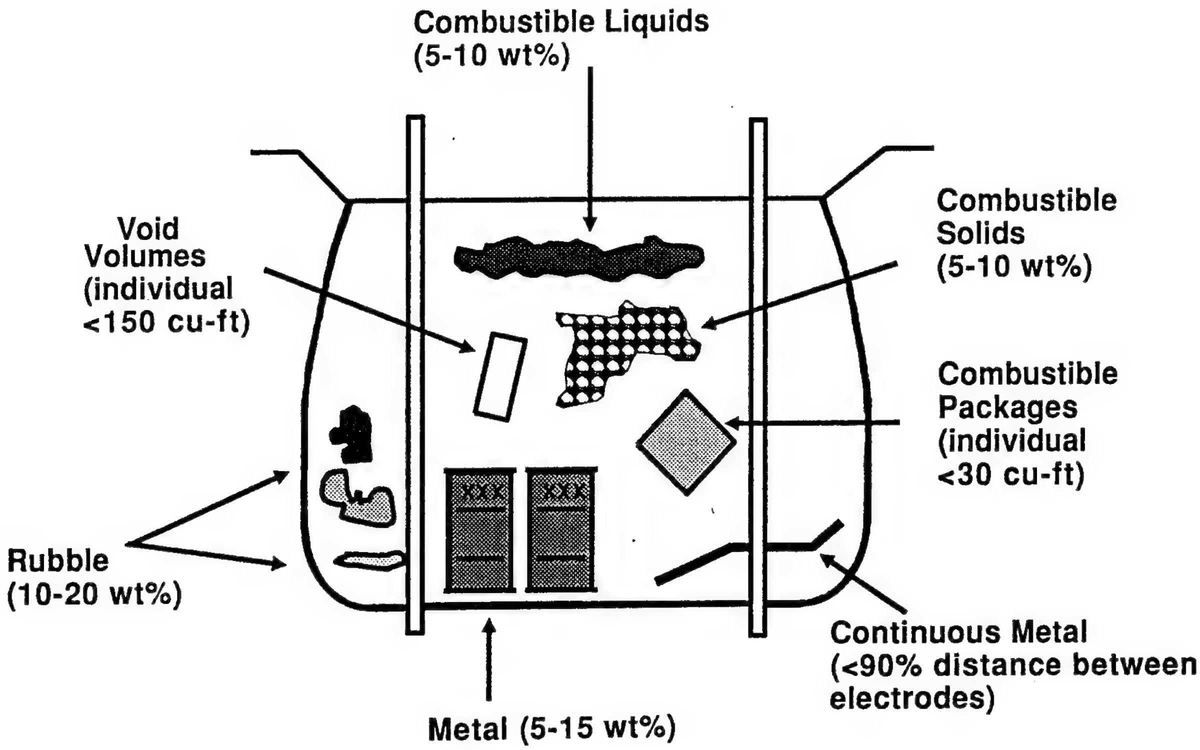


FIGURE 7. General Limits for Inclusions Within Volume to be Treated

area supporting the hood should not slope more than 5%. With special equipment adaptation, the treatment area may be up to 6 ft above or below the level of the treatment trailers. In addition, care should be taken to prevent surface or rainwater from flowing into the treatment area. Site preparation to accommodate these equipment needs can be performed using standard earth-moving equipment.

I. Presence of Above- and Under-Ground Structures

The ISV process should be performed sufficiently distant from engineered structures to prevent unintended damage to them by the processing. The two primary concerns are thermal effects and affects due to soil densification and related subsidence.

During cooling of a single large ISV melt, heat transfer into surrounding soil will result in a lowering and flattening of the melt-soil thermal gradient that was present during processing.

For example, while during processing the 100°C isotherm exists 6 to 12-in from the 1600°C (or higher) melt surface, this isotherm will move out into the soil during cooling. For a typical melt and average soil, the 100°C isotherm may move as far as 5 to 7-ft from the residual monolith. Figure 8 illustrates the flattening of the thermal gradient during cooling. This figure should be considered as a typical example only.

The cooling of ISV settings at specific sites will vary; evaluation of the cooling thermal gradient is performed during remedial design as appropriate. A rule of thumb for initial estimation purposes is that the ISV melt should not be located closer than 15-ft to underground utility lines and structures that could be damaged by temperatures above 100°C. Individual elements should be considered relative to their ability to withstand a thermal field (e.g., dehydration temperature of concrete). Protective means may be employed if desired.

In like manner, remedial design must consider expected soil subsidence relative to aboveground structures (e.g., undermining of soil under a floor slab or foundation). The ISV process has not been observed to induce electrical potential or currents in nearby metallic structures or utility lines such as piping or wiring.

J. Electrical Power Supply

The large-scale ISV equipment system requires 3-phase electric power at either 12,500 or 13,800 volts. The equipment is controlled to draw about 3,750 kw during operation, which corresponds to a specific power consumption averaging 0.45 kwh/lb of soil treated, for most soils. The electric power may be supplied by public utility, or it may be diesel-generated onsite; the choice between the two is an economic decision. The process may utilize interruptible power. Once a melt is established, the process may be restarted after a power shutdown or loss, as long as there remains a molten path between the electrodes. For example, assuming a 200 to 300 ton melt exists, the process may be restarted after being shut down for several days. If the melt is allowed to solidify before restarting, then it must be restarted at the surface. In this case the placement of some loose soil and a new starter path would be necessary.

It is generally not economically advantageous to utilize off-peak power only, for example operating only a portion of each day. While the process could feasibly be restarted each day, the heat losses incurred during idle periods typically would offset or exceed the savings obtained by operating only during off-peak periods.

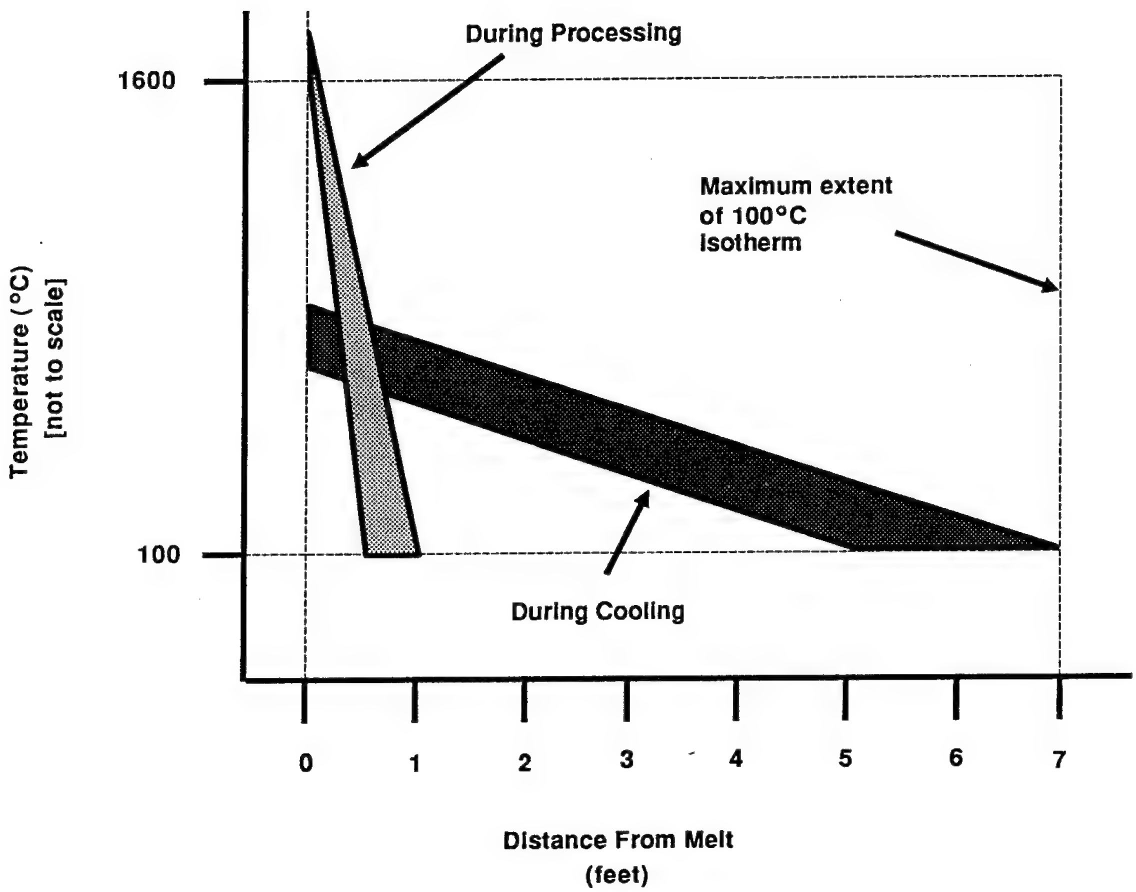


FIGURE 8. Relationship of Thermal Gradient to Distance From Melt During and After Treatment

The amount of power consumed by the ISV process is not significant relative to the power available from public utilities throughout the United States. In fact, public utilities have been found to be eager to provide the power and willing to negotiate reasonably discounted rates (i.e., equivalent to large industrial usage) for ISV applications.

K. Risk Management

The onsite and in situ nature of the ISV process provides a degree of safety not possible with remediation alternatives requiring excavation, transport, and/or aboveground processing. In addition, the ISV processing system utilizes a large number of safety features and equipment items specifically for the purpose of ensuring operations safety.

Geosafe assesses potential projects prior to quotation to ensure that there is no significant potential for environmental release to the air, surrounding soil, or groundwater, or for injury to others. The risk management analysis considers site demographics to ensure the process may be safely applied relative to industrial and public population groups. Geosafe's risk management analysis also considers the need to meet deliverable requirements for the client. Considerations include: 1) ensuring completion of the volume to be treated, and 2) attaining adequate residual product quality. Any possibility of the process to produce unforseen results, new types of secondary waste, or any other undesirable effect(s) are fully assessed.

Geosafe's risk assessment procedure provides a systematic analysis and evaluation of all project activities to ensure that correct risk management decisions are made for a project. The procedure first involves review of the project to identify the types and magnitude of pertinent exposure. The next step involves assessing the type, magnitude, and possible consequences associated with any exposure. Concurrently, the procedure involves identifying how the exposure could occur, and how it may be prevented or controlled. All of this information is then analyzed relative to pertinent regulations and the client's and Geosafe's acceptability standards. This analysis results in a risk management plan for the project. Geosafe's risk management planning is done in full concert with regulatory risk management requirements.

Once an ISV remediation project is underway, Geosafe's risk management program involves re-evaluation of preliminary risk assessments based on actual onsite project performance. Revisions are made as necessary to ensure regulatory compliance.

IV. PERFORMANCE RELATIVE TO EVALUATION CRITERIA

This section presents information on ISV technology that is organized into the topics subject to evaluation during alternative technology feasibility studies (referring to EPA guidance for remedial investigations and feasibility studies).

A. Short-Term Effectiveness

This evaluation criterion is concerned with: 1) protection of the community during remedial actions, 2) protection of workers during remedial actions, 3) environmental impacts, and 4) time until remedial response objectives are achieved.

The in situ and onsite nature of the ISV process are particularly advantageous relative to the first three considerations listed above. Since the process is employed onsite, there is no transportation of hazardous materials through local neighborhoods or over public highways. Since the process is performed in situ, exposure of workers, the public, and the environment to contaminated materials is minimized. This feature is particularly important at sites containing highly volatile organics that may be released to the air during excavation. The ISV process may involve some excavation and staging of contaminated materials for economic or technical reasons; however, in most cases the amount of surface handling is not equal that required for typical aboveground technologies. The ISV process also does not require aboveground pretreatment that could result in dusting air emissions as is typical of many technologies.

The large-scale ISV equipment operates in the 4 to 6 ton/hr range. Operations are conducted around-the-clock with the exception of an average 16-hr downtime between settings. Therefore, average weekly production from a single machine is expected to be in the 600 to 800 ton/wk range. If more rapid remediation is desired for a specific project, additional ISV machine(s) may be applied to obtain multiples of the single machine throughput rate.

B. Long-Term Effectiveness and Permanence

This evaluation criterion is concerned with: 1) magnitude of long-term risk, 2) adequacy of controls, and 3) reliability of controls. Controls in this context refers to containment systems and institutional (management) controls to ensure long-term safety relative to residuals left after remediation of a site.

The ISV technology is superior in this area because: 1) hazardous organics and some inorganics (compounds) are irreversibly destroyed or removed from the treatment volume, and 2) remaining hazardous inorganics (elements) are chemically incorporated into a residual product capable of withstanding long-term (i.e., geologic time periods) environmental exposure. Through these means, the ISV process is truly a permanent remediation solution.

As presented in Section II and Appendix A, the ISV process is capable of irreversibly destroying and/or removing hazardous organics from the treatment volume. The ISV process is also capable of securely immobilizing hazardous inorganics in the residual glass and crystalline product. The vitrified waste form has been subjected to a variety of leach tests, including EPA's EP-Tox and TCLP. These tests show a uniformly low leach rate for heavy metals of about 5×10^{-7} gm/cm^2/day or lower. Based on extensive testing, the vitrified material appears to be qualified for delisting under the provisions of either the EP-Tox or the TCLP.

Another indication of the durability of the ISV waste form is found in a study of the weathering of obsidian, a naturally occurring (volcanic origin) glass-like material physically and chemically similar to the ISV waste form. In the natural environment, obsidian has a hydration rate constant of 1 μm^2 to 20 μm^2/1000 yr. A linear hydration rate of 10 μm^2 produces a highly conservative estimate of a <<1 mm hydrated depth for the ISV waste form over a 10,000 yr time span. In addition, the formation of hydration products will encase the monolith in a thin hydration rind which will inhibit further hydration.

Data for the release of sodium from vitrified Hanford Site soil during a leach test at 194°F are available for durations of 7, 14, and 28 days. Because the sodium is soluble in the leachate, its normalized release is a measure of the extent of hydration of the glass and, in particular, the normalized release divided by the density of the glass indicates depth of hydration. If the glass is assumed to hydrate according to the same parabolic rate law as has been found for obsidian, then the square of the depth of hydration divided by the duration of the test should be constant. Using previous test data, the result of this calculation increases between the 7 and 14 day data, but is then constant between the 14 and 28 day data. Taking this final value and using the density of the glass, the hydration rate at 194°F appears to be about 2 μm^2/yr. In the literature on field studies of obsidian hydration, the rate is found to obey an Arrhenius relation with an activation energy of 20 kcal/mole. Applying this to the ISV glass hydration, we can predict rates of 5 μm^2/1000 yr at 77°F (e.g., for glass exposed to the air) and 1 μm^2/1000 yr at 50°F (e.g., for glass buried underground). These values are comparable to those found for obsidian hydration rates in the field for similar average weathering temperatures.

The long-term stability of obsidian in nature is controlled by three mechanisms: 1) alteration (weathering), 2) devitrification (recrystallization), and 3) hydration (water absorption). A review of the literature indicates that the usual controlling mechanism is devitrification. Studies of the mean age of natural glasses indicate that obsidian has a mean life of about 18 million years. Considering the similarity of the ISV waste form to obsidian, we can reasonably postulate that the mean life of the vitrified material would be in the realm of geologic time (i.e., thousands to millions of years).

The ISV residual product is predominantly a glass with an atomic structure that is random, rather than the highly structured nature of a crystalline material. This leads to another benefit: the fracture mechanism is conchoidal (i.e., the glass does not crack along crystalline boundaries, but rather will crack in a spalling or self-terminating way.

Based on EPA tests of ISV product incorporating waste from a Superfund site, the ISV product has been shown to have excellent structural strength, averaging about 10 times the strength of unreinforced concrete in tension and compression; and it has been demonstrated to be unaffected by freeze/thaw and wet/dry cycling. There is no other technology that is capable of producing a residual immobilization product with such outstanding environmental exposure properties. It is fully expected that the ISV residual product may be delisted (i.e., declared no longer hazardous); at that point, the need for long-term concern about the residual would cease.

C. Reduction of Toxicity, Mobility, and Volume

This evaluation criterion addresses the statutory preference for selection of remedial actions that employ treatment technologies permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances as their principal element.

The ISV process reduces toxicity of hazardous wastes by: 1) irreversibly destroying or removing hazardous organic materials, and 2) by chemically incorporating hazardous inorganics into the residual glass and crystalline product. For the case of organic contaminants, destruction by pyrolysis is an ultimate form of detoxification. During ISV of typical organics, a very large fraction (typically 99.9 to 99.995 wt%) is destroyed by pyrolysis while substantially all of the remainder (e.g., <0.1%) is volatilized from the treated volume and is captured by the off-gas treatment system; this system typically provides >99.9% removal of the <0.1% organics present in the off-gas. Total system DRE is thus typically >99.9999%. Periodically the organics captured in the off-gas treatment system are recycled to a subsequent ISV melt wherein >99.9% additional destruction is obtained on that material. In this manner the ISV process can be used to destroy substantially all of the hazardous organics at a site.

Since hazardous inorganic elements (e.g., Pb) cannot be destroyed, their most effective detoxification can be achieved by immobilization, as occurs in the ISV residual product. The vitrification process is unique in that it chemically incorporates the inorganics rather than just immobilizing them by encapsulation or chemical stabilization means.

EPA testing has indicated acceptable biotoxicity of the ISV residual product relative to near surface life forms. These test results were obtained on ISV product resulting from processing a mixture of hazardous organic and inorganic wastes from the Western Processing Superfund site in Washington State. In contrast, three chemical stabilization waste forms, containing the

same starting waste materials and which were tested at the same time, failed the biotoxicity tests.

Mobility reductions are not pertinent for hazardous organics under the ISV process since they are destroyed or removed from the material being treated. Reduction in mobility is pertinent to hazardous inorganics. These materials are chemically incorporated into the residual ISV product, which has structural and chemical leaching properties that maximize long-term immobilization performance.

Vitrification is the only known process that results in significant volume reduction of inorganic soils, sludges, tailings, and sediments. During ISV, volume reduction occurs through elimination of the void volume that is inherent within particulate mixtures and through conversion of some materials to gases, which evolve from the volume. Typical soils possess 20-40% void volume; at a minimum, that amount of volume reduction occurs during the ISV process.

Geosafe believes that the ISV residual product is absolutely unequalled in providing permanent detoxification, immobilization, and volume reduction of hazardous organic and inorganic materials. Geosafe considers the ISV process and residual product to fully meet the congressional mandate for performance of remediation technologies in this area.

D. <u>Implementability</u>

This evaluation criterion addresses: 1) the technical and administrative feasibility of implementing an alternative, including the ease of undertaking additional or related remedial action and monitoring the results of remediation, and 2) the availability of various services and materials required during its implementation.

The ISV technology is classified by EPA as an innovative technology: one that has been developed to large-scale and is ready for commercial deployment, but for which there is not a significant commercial experience base. Because of this status, it is necessary to thoroughly evaluate all aspects of ISV applicability for a specific site prior to commitment to large-scale operation. Geosafe recommends that treatability testing be performed as an important part of the applicability evaluation.

The objectives of treatability testing include: 1) demonstration at small-scale that the ISV process is applicable to the specific soil-waste mixture present at the site, 2) generation of specific operational performance data (e.g., fusion temperature, melt rate, off-gas composition, organic DRE) needed to support remedial design, full-scale cost estimating, and permitting/compliance

efforts; and 3) generation of data and samples for use in community relations efforts. Treatability testing involves shipment of actual contaminated and clean samples from the site to Geosafe's designated laboratory for testing.

Data from greater than 70 ISV tests performed at various scales indicate that bench-scale treatability tests yield the data necessary for applicability evaluations. Since the ISV process has already been scaled up and demonstrated as operational at large-scale, the types of information required for applicability evaluations (e.g., fusion temperatures, melt rate, off-gas composition) are satisfactorily obtained at small-scale.

Depending on the results of treatability testing, Geosafe may determine that demonstration testing is also advisable before commercial operation at a site. Typically, such demonstration settings may be performed at large-scale, on actual waste, onsite. In such situations, satisfactory completion of the demonstration settings would warrant continuation of remediation at the site on a commercial basis.

The implementability criterion is also concerned with the possible impact a technology alternative may have on the performance of additional or related remediation at the site. The accessing of groundwater after ISV treatment is one such consideration. In the event it is desired to access groundwater under the residual monolith after ISV remediation, such access can be gained by drilling out one or more electrode locations in the monolith. It is reasonable to consider utilization of ISV for treatment of a contaminant source located above the water table, followed by groundwater remediation. At large sites, groundwater remediation and ISV may be performed concurrently. The ISV residual itself can be monitored by core drilling of samples and by monitoring the soil adjacent to the monolith produced.

Regarding availability of services, Geosafe expects to have one ISV machine operational during the first quarter of 1989. Additional machines will be procured as the expected market for ISV materializes. Geosafe is able to procure additional machines within 4 to 6 mos, which is significantly less than the time typically required to perform treatability testing, permitting/compliance, and remedial design efforts prior to onsite operation. Geosafe is willing to consider purchase of new machines for specific projects if the client has a schedule need that cannot otherwise be met by existing equipment. Geosafe will make schedule commitments for its machines given a corresponding commitment by the client.

Geosafe does not anticipate difficulty acquiring and maintaining field operations crews for its ISV systems. Geosafe conducts its

own specialized ISV training program at its training center in Richland, Washington.

Whereas Geosafe will focus on offering direct ISV remediation services, as opposed to general remediation services, it will work together with general remediation contractors, either as a prime or subcontractor, to provide total project remediation services as needed by clients. Because Geosafe holds worldwide exclusive rights to the ISV technology in the field of hazardous waste remediation, it is not possible for a client to obtain competitive bids for the ISV portion of a project. However, competitive bidding is possible on the related site preparation and general contractor support work. Geosafe may be subject to cost justification analyses on U.S. Government projects as required by the Federal Acquisition Regulations.

E. Cost

This evaluation criterion is concerned with: 1) direct and indirect capital costs, and 2) annual costs (maintenance and operating) as necessary to ensure the continued effectiveness of a remedial action.

A typical remediation project utilizing ISV includes the work elements listed in Table 3. With reference to the table, those activities designated as support are typically performed by others with technical support services provided by Geosafe; such services are offered on an hourly charge basis at prevailing rates for the staff providing the services. Geosafe will provide estimates of time required for technical support activities on a site-specific request basis; such costs typically fall in the $25-75,000 range. Note that Geosafe does not provide site characterization services, and prefers to have site preparation and restoration activities performed by others.

The cost of treatability testing varies depending on the number of tests to be performed and the specific contaminants of concern. Most treatability tests involve single, bench- or engineering-scale ISV melts which are adequate for producing the needed applicability data; the typical time required for testing and analysis of results is 6 to 10 wks after placement of a test contract. Additional tests, that may be performed under the same project preparatory work, can cost significantly less. Individual treatability tests typically cost in the range of $20-25,000 plus analytical costs, which can vary significantly depending on the contaminants involved. Geosafe will provide a treatability test quotation for specific sites upon request.

Mobilization/demobilization costs cover the following project activities: 1) transport of equipment from its base or current location, 2) onsite erection, 3) readiness testing, 4) post-

TABLE 3. ISV Activities Related to Stages of a Superfund Project

Superfund Stage	Work Activity	Geosafe Involvement
RI/FS	Treatability Test	Perform
ROD	None	NA
RD	Remedial Design	Support*
	ARARs Compliance	Support*
	Community Relations	Support
RA	Site Preparation	Support
	Equipment Mobilization	Perform
	Vitrification Operations	Perform
	Equipment Demobilization	Perform
	Site Restoration	Support
O&M	Post-Process Sampling/ Monitoring/Delisting	Support

* Geosafe may perform ISV portion of this activity

project decontamination, 5) disassembly, and 6) transport back to base location. The large-scale ISV equipment system is contained on three trailers which are capable of travelling at normal highway transport speeds and of achieving typical daily mileage. Once onsite, the equipment can be made operational within 4 days. About 5 days is necessary for decontamination, tear-down and preparation for transport. Mobilization/demobilization costs are site location-specific. Initial estimates of total mobilization/demobilization costs may be made on the basis of a base cost of $50-60,000 plus $50-60/mi from Geosafe's Richland, Washington base location. Geosafe should be contacted for specific estimates whenever possible.

The cost of vitrification operations is also highly site-specific. The major determinants of cost include the following:

- The amount of site preparation and staging work required, if any
- Specific properties of the waste-soil to be processed (e.g., dry density)
- Volume of material to be processed
- Depth of processing

- Moisture content
- Unit-price of electricity
- Season of the year.

Depth of processing is a significant cost variable that relates directly to the ratio of operating time to downtime. Since the ISV process is batch- or setting-based, the equipment must be moved between settings. The process economics are favored by deeper depths which increase the ratio of operating time to the time required for movement between settings. For shallow contamination (e.g., only a few feet), it is usually more cost-effective to remove and stage the material into a deeper configuration for processing.

Moisture content is one of the most significant variables affecting vitrification costs, which can vary $50 to 75/ton between dry soil and fully saturated soil. Thus, it is in the client's best interest to keep the treated volume as dry as practicable prior to processing. In some cases (e.g., wet sediments) the costs of pre-drying (e.g., staging for gravity dewatering) the material may be justified when compared to the cost of driving the water off during ISV.

The cost of electricity is also a major variable affecting total ISV costs. Generally it is more economical to utilize utility-provided power if it can be obtained for less than $0.07 to 0.08/kwh. In and above this range, consideration should be given to utilizing diesel-generated power, the cost of which depends primarily on the current price of diesel fuel. A fixed cost for establishing the electric service onsite may also be required, if such service does not already exist.

Geosafe has found that the quantity of power required by a large-scale ISV system (i.e., 3,750 kw) is readily available throughout the continental United States, and that most utilities are quite eager to provide the power needed at reasonably discounted prices, typical of large industrial usage (usually about 50% of residential rates). The result is that utility power is usually the preferred source, with the possible exception of remote locations which are distant from power lines. Utility rates are readily available from the marketing departments of various local utilities. Geosafe is willing to contract for the power directly with the utility, or to work on the basis of client-supplied electric power.

Given data or assumptions for a project in the variable areas listed above, Geosafe is able to model the project and prepare a cost estimate with an accuracy significantly better (i.e., +30%,

-15%) than standard feasibility-quality (i.e., +50%, -30%). Of course the accuracy of Geosafe's estimates depend on the accuracy of the data or assumptions provided. Thus, it is wise to perform treatability and/or other tests as necessary to verify any assumptions used.

Geosafe will provide vitrification cost estimates on a cost/ton basis, but provides quotations for vitrification operations on a megawatt-hr-consumed basis. This latter basis accommodates variations within a site (e.g., moisture content, soil fusion properties) that may not be accurately defined by available site characterization information. Geosafe's quotes for vitrification operations include all costs associated with the vitrification, including equipment amortization, electrodes and their placement, movement between settings, supporting analytical work, preventative maintenance, and other operations-related activities. Clients are provided certified energy consumption data in support of operations billings.

As indicated above, there are many variables that can impact the cost of vitrification operations. Geosafe prefers to provide site-specific estimates for potential applications rather than to utilize a rule-of-thumb value for operations costs that may not be pertinent for a specific site. Geosafe will provide operating cost estimates upon request. The basic information needed to develop a cost estimate is presented in Appendix C.

Remediation by ISV eliminates some typical site restoration needs. Since the residual ISV product is essentially impermeable and nonleachable, there is no technically-based need for installation of a RCRA cap over the treated volume. Placement of clean backfill to the depth required by future land use plans should be sufficient restoration.

Regarding annual (or maintenance) costs, it is not anticipated that there should be such costs associated with the ISV portion of a remediation project beyond the point of attaining delisted status for the treatment volume, or of obtaining an exemption from further monitoring after, say, 2 to 3-yrs of monitoring. Since the ISV process is a truly permanent solution, the ISV-treated volume should be capable of being put to alternative use, except as impacted by remedial or monitoring activities associated with other technologies being employed at the site, or because of continuing hazards associated with the residual product (e.g., radioactive materials).

The total cost per ton of material processed in an ISV project depends significantly on the size of the project. Of the cost categories discussed above, only the vitrification operations costs vary directly with site size; all other cost types are predominantly fixed in nature. The relationship of fixed costs to site size is illustrated in Figure 9. This figure assumes the

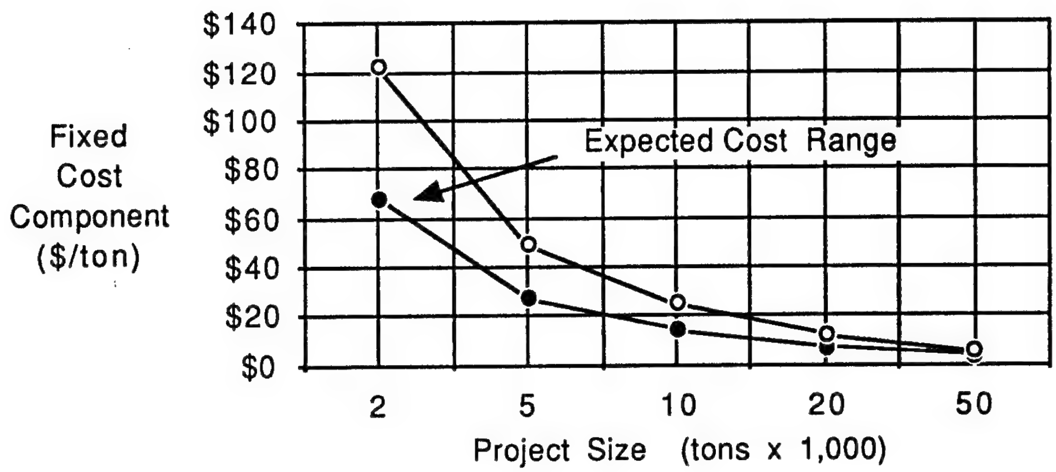


FIGURE 9. Impact of Project Size on Fixed Cost Portion of Total Costs

following cost ranges for illustrative purposes: treatability testing ($35-45,000), technical support ($25-75,000), and equipment mobilization/demobilization ($75-125,000).

F. Compliance with ARARs

This evaluation criterion is concerned with evaluating alternative technologies relative to compliance with: 1) chemical-specific ARARs, 2) action-specific ARARs, 3) location-specific ARARs, and 4) appropriate criteria, advisories, and guidances. Geosafe will include consideration of ARARs, if they are available, in its applicability evaluation of specific projects. In addition, Geosafe will provide support to the client or his contractor as requested for preparation of needed ARARs compliance documentation. Prior experience has indicated the ISV process is quite capable to satisfy typical state ARARs.

G. Overall Protection of Human Health and the Environment

This evaluation criterion provides a final check to assess whether an alternative meets the requirement that it is protective of human health and the environment. This final check includes a summary review of factors assessed under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs. A summary

of ISV's characteristics that contribute to its protection of Human Health and the Environment include:

1) elimination of remaining risk from the treated volume due to ISV's permanent destruction of hazardous organics and immobilization of hazardous inorganics,

2) permanence of the ISV residual product which is expected to exhibit excellent structural, weathering, leaching, and biotoxicity properties for geologic time periods,

3) permanent volume reduction,

4) avoidance of public and occupational exposure due to the in situ and on-site nature of ISV,

5) ability to satisfy ARARs.

H. Regulatory Acceptance

This evaluation criterion evaluates the technical and administrative issues and concerns that a state or support agency may have regarding application of ISV to a specific site.

There already exists significant awareness and knowledge of the ISV technology within certain federal and state regulatory organizations. ISV has been selected for evaluation under EPA's Superfund Innovative Technology Evaluation (SITE) Program, and, at the time of this writing is being considered for inclusion in the State of California's Remedial Technology Assessment Program (RTAP). In addition, EPA has included ISV as an innovative technology to be considered for application to contaminated soil sites under the Remedial side of the Superfund Program. ISV is being evaluated by the Removal Program side as well, and several removal projects are anticipated to occur during 1989. Geosafe will support clients as requested during evaluation of regulatory acceptance.

I. Public Acceptance

The ISV process and residual product enjoy excellent acceptance where the public and potential clients have obtained an understanding of it. Even though the process has had limited commercial application to date, there has been significant media inquiry and reporting on it, and it has been presented a number of times in various public hearings.

ISV has several advantages that relate to public acceptance, including:

1) its onsite and in situ application nature,

2) the unequalled quality of its residual product,

3) a non-threatening appearing (and sounding) onsite equipment system,

4) the absence of any prior adverse record of misapplication or failure to perform,

5) a very credible scientific basis and state of development by the U.S. DOE and Battelle Memorial Institute, and

6) Geosafe's "safety-first" and application conservatism policies.

Geosafe believes that the public intuitively recognizes the in situ (in the ground) performance of ISV is safer than processes performed ex situ. In like manner, there is a public familiarity with glass and natural obsidian, and a recognition that they are essentially not degraded by the environment; this public perception together with technical data on the ISV residual product supports the public recognition that contaminants are permanently and harmlessly bound in the ISV residual product.

It is noted that neither ISV nor Geosafe have any adverse performance record that can affect public acceptance of ISV. Geosafe recognizes that other generic technologies (e.g., incineration) have suffered in the public acceptance area due to long-prior public image difficulties (e.g., a smoke-stack image). Recognizing the importance of the record to public acceptance, Geosafe intends to work with clients, regulators and the public to maintain a superior record.

The extensive development program leading to the commercialization of ISV technology, and the excellent technical reputation of the developing organizations (e.g., U.S. DOE, Battelle), also provide a significant degree of credibility to the technology's acceptance. The technology has undergone significantly more development and test work than most other new technologies being introduced to the hazardous waste remediation marketplace.

Geosafe will support clients as requested in the area of community relations programs, public hearings, and other activities associated with public concern and acceptance.

V. QUALITATIVE COMPARISON TO ALTERNATIVES

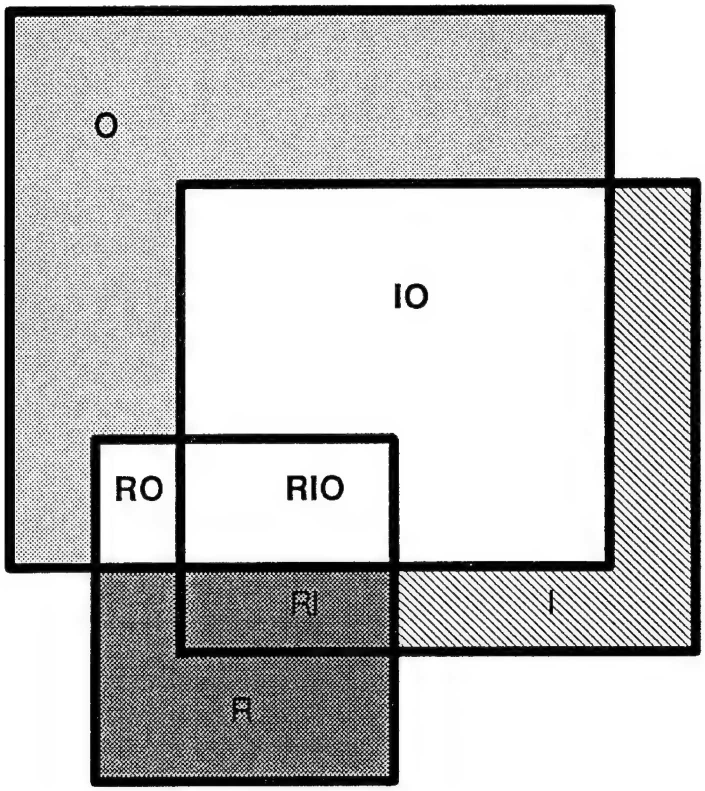
The ISV technology possesses very broad applicability to remediation of contaminated soils, perhaps more than any other current remediation technology. However, ISV may not be the most appropriate technology for some sites because of site-specific conditions and cleanup requirements; and in some cases less effective technologies may satisfy specific requirements at lesser cost. It is recognized that a specific comparative evaluation is typically prepared for individual projects as part of the feasibility study activity.

A comparison of ISV to the alternatives of landfill, chemical stabilization, and incineration is presented as Appendix D. This comparison should be recognized as generic and qualitative in nature, yet typical for many applications involving remediation of contaminated soils.

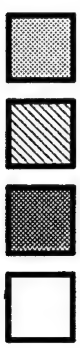
The following comparative discussion between ISV and other major remediation technologies refers to Figure 10, which employs the designations O, I, and R to indicate soils contaminated with hazardous organics, inorganics, and radioactive substances respectively. The figure also indicates the principal types of technologies considered for remediation of the generic waste type or mixture of types.

The comparison of ISV to alternative technologies is based on the congressional mandate that EPA should strive to develop and apply technologies that provide permanent remediation solutions including reduction in toxicity, mobility and volume, and should give preference to technologies that can be applied onsite and in situ, if possible. The previous standard of containment (e.g., excavation and redisposal in a licensed landfill) is not recognized as an alternative remediation technology in the context of the congressional mandate. That is because containment: 1) provides only temporary isolation of hazardous materials from humans and the environment, 2) involves significant public and occupational exposure risk due to the requirements for excavation and transportation, usually offsite, 3) provides no detoxification or volume reduction (although it may provide a temporary reduction of effective mobility), and 4) increases long-term liability exposure for waste owners/generators and the public at large. Containment is considered an expedient measure only for providing temporary isolation of hazardous substances; it should be used only as a last resort.

The first important observation relative to Figure 10 is that ISV technology is applicable, under appropriate conditions, to all the basic waste types and their possible mixtures; no other technology is so broadly applicable for contaminated soil applications.



Principal technologies employed by type of waste (contaminated soil/sludge/sediment/tailing applications):



- **Type O** - Thermal Destruction, Chemical/Thermal Extraction, Biological Degradation
- **Type I** - Immobilization, Chemical Stabilization, Chemical/ Thermal Extraction
- **Types R, RI** - Immobilization, Chemical Stabilization
- **Types IO, RO, RIO** - Thermal Destruction, Immobilization, Chemical Stabilization

Note: ISV technology is applicable to all types of waste. ISV simultaneously provides thermal destruction and immobilization treatment.

FIGURE 10. Comparative Applicability of ISV for Various Types and Type-Mixtures of Contaminated Soils

For the case of organics-only contamination (type O), the current standard is thermal destruction, usually as performed by incineration (e.g., fluidized bed, rotary kiln, infrared). ISV may be considered a thermal destruction technology relative to organics; however, there are distinct advantages that ISV exhibits over incineration; such are listed below.

1) The ISV process pyrolyzes (breaks down into non-hazardous components) hazardous organics whereas incineration oxidizes the hazardous organics themselves.

2) The ISV process does not add any hydrocarbon fuel to the process nor rely on oxidation of the contaminants; therefore, the volume of off-gases to be cleaned up, and the corresponding difficulty of assuring stochiometric oxygen levels and off-gas cleanup treatment, is significantly less (by orders of magnitude) for ISV than for incineration.

3) The ISV process typically does not require excavation as does incineration (although it may be economically advantageous in some applications).

4) ISV does not require pre-treatment of waste and is able to accommodate inclusions of various types. Many incineration operations require expensive crushing, shredding, mixing and/or other pre-treatment methods to render the waste compatible with the treatment device.

5) The in situ nature of ISV provides enhanced occupational and environmental safety compared to the ex situ performance of incineration.

For the case of inorganics-only contamination (type I), the current standard is chemical stabilization (i.e., adding of cement or similar materials to solidify and stabilize). Relative to inorganic contaminants, ISV technology is considered as an immobilization technology which goes significantly beyond stabilization. The major differences between ISV and chemical stabilization are listed below.

1) The ISV process immobilizes inorganic contaminants through chemical incorporation into a high integrity glass and crystalline residual product; chemical stabilization stabilizes inorganic contaminants through encapsulation and/or weak chemical bonding and solidification into a cement-like solid.

2) The ISV immobilization is essentially permanent (i.e., geologic time periods), whereas chemical stabilization

is a temporary solution with widely varying and relatively short life expectancies (i.e., less than 100-yrs).

3) The in situ nature of ISV avoids the excavation and aboveground operations typically required by chemical stabilization; this results in increased occupational, public, and environmental safety for ISV applications.

4) The ISV process produces a residual product that possesses acceptable biotoxicity relative to near-surface life forms; the chemical stabilization product is toxic to these life forms.

5) The ISV process results in a significant volume reduction (e.g., 20 to 40 vol%) in most soils whereas chemical stabilization involves a significant volume increase (e.g., 20 vol%) due to the addition of cementitious chemicals to the soil.

Geosafe does not believe that there is an established standard technology type for remediation of radioactively-contaminated soils (type R). Rather, such soils are generally being contained/stored either where located, in landfills, or in aboveground storage, until such time that remediation standards are established for them. It is noted that melter-based vitrification is the standard for immobilization of some types of defense high-level radioactive wastes; however, such wastes are not the radioactive wastes of concern here. The ISV technology grew out of that melter-based technology.

Considering that many radioactive wastes are threatening both because they are toxic heavy metals and because they are radioactive, there is general consensus that they require very secure isolation from humans and the environment. The ISV process relates to the heavy metal radioactive contaminants as it does to nonradioactive inorganics. Whereas ISV is not able to "turn off" the radioactive decay (no process is), it is able to provide the ultimate in long-term immobilization through chemical incorporation of the radioactive elements within the residual product. The monolithic structure of the ISV product also serves to minimize possible exposure of humans and the environment to the residual. It does that both through attenuation of some radiation, because of the large monolithic mass, and through providing a residual material which is very difficult to inadvertently violate.

The ISV process holds significant potential for application to one very pressing radioactive waste problem, that being human exposure to radon gas generated by decay of manmade or naturally occurring radioactive materials. The ISV process has been found capable of chemically incorporating the source of radon gas,

radium-226, within the residual product. Thus, when radon-222 is generated through the natural decay of radium-226, the radon is held within the glassy structure of the ISV product sufficiently long to allow the radon to decay further, back to a solid state. Tests of ISV product on radon-generating waste have indicated a four order of magnitude reduction (factor of 10,000) in radon emanation rate between untreated soil and the ISV residual product. ISV certainly holds significant advantages for remediation of radioactive soil sites.

Most hazardous waste-contaminated soil sites include a mixture of organic and inorganic waste types (type IO). ISV is directly applicable to such sites, typically without additional processing time or cost. Alternatively, the only other way to handle such wastes is to sequentially utilize two or more technologies, first to remove or destroy the organic portion, and then to stabilize the inorganic-contaminated residual from the first processing (e.g., incineration followed by chemical stabilization). The comparative advantages of ISV in this case are the same as for the individual incineration and chemical stabilization comparisons, with the added advantage of lower total cost.

The radioactive plus organic (type RO) and radioactive, inorganic, and organic mixture (type RIO) cases are very similar to the above situation for type IO waste. ISV provides the unequaled immobilization benefit for the radioactive and inorganic contaminants while simultaneously destroying/removing the organics. ISV offers the important possibility of enabling reclassification of RO and RIO wastes from mixed waste to radioactive waste, through destruction/removal of the organic content. Incineration is technically possible for the organic portion of the contaminants; however, it is very difficult to obtain permit authority to incinerate radioactive materials, for obvious air emission reasons. Chemical stabilization may be applicable for stabilization of the inorganic portion in cases where the superior immobilization product of ISV is not required.

The radioactive plus inorganic (type RI) waste type suffers difficulties as indicated above for radioactive wastes in general. The comparisons above between ISV and chemical stabilization apply here as well.

VI. APPENDICES

APPENDIX A - Discussion of the Disposition of Hazardous Materials During ISV Processing

APPENDIX B - Discussion of Possible Waste Arrangements for ISV Processing

APPENDIX C - Information Needed for Development of ISV Cost Estimate

APPENDIX D - Qualitative Comparisons of ISV with Landfill, Chemical Stabilization, and Incineration Technologies

APPENDIX E - Discussion of ISV as a Containment Technology

APPENDIX A

DISCUSSION OF THE DISPOSITION OF HAZARDOUS MATERIALS DURING ISV PROCESSING

APPENDIX A

Discussion of the Disposition of Hazardous Materials During ISV Processing

The primary objectives of ISV processing include: 1) destruction and/or removal of hazardous organics present within the treatment volume, 2) chemical incorporation and/or physical encapsulation of hazardous inorganics within the residual glass (obsidian-like) product, 3) reduction of volume containing the hazardous contaminants, and 4) performance of the processing without adverse environmental, public safety, or land use impact. The degree to which those objectives have been satisfied is determined by: 1) quantifying the destruction and removal efficiency (DRE) of the organics treated, 2) assessing the weathering (leaching, wet/dry, freeze/thaw), biotoxicity, and structural properties of the residual glass product relative to its immobilization of the hazardous inorganics, 3) measuring the volume reduction achieved by the processing, and 4) comparing ISV system emissions to established emission limits.

Understanding the ultimate disposition of contaminants during ISV processing is critical to the successful application of the ISV technology. The disposition of contaminants is dependent upon many variables, the most important of which may be grouped into the categories of: 1) pre-melt soil properties, 2) contaminant quantities and properties, and 3) molten zone properties and conditions. Individual contaminants may respond to the system of processing variables in numerous ways, including: 1) change of state, 2) physical movement, and 3) physical/chemical reaction. A general summary of the process conditions, and discussion of the three types of contaminant response to those conditions are presented below.

Process Conditions and Melt Environment

The ISV process involves electric melting of soil. Joule heating of the molten mass occurs as electric power is passed between two pair of electrodes. Heating of the complete molten mass is aided by convection currents within the melt. Heat is transferred from the molten mass to the adjacent soils by conduction.

Ionic conditions within a soil melt typically result in a strong chemically-reducing environment. Most soils consist of the products of weathering of rocks which, especially igneous and metamorphic rocks, consist of an assemblage of minerals (primarily silicates and oxides) which can be expressed as major oxides (e.g., SiO_2, Al_2O_3, Fe_2O_3, CaO). Thus, during ISV, the melt consists of a mixture of oxides, and compounds and elements associated with the contaminants present in the soil.

A very steep thermal gradient is present in the soil adjacent to the molten zone. With a melt temperature in the range of 1,600 to 2,000°C, the 100°C isotherm is usually within 6 to 9 inches of the melt. The melt advances in the range of 1 to 2 in/hr. The zone between the 100°C isotherm and the melt is devoid of liquid water and is termed the dry zone. Because the liquid water has been removed, the dry zone has relatively higher vapor permeability than does the adjacent, wet soil.

Figure A-1 illustrates the basic process conditions described above.

Contaminant Response to Processing

Change of State:

Contaminants may exist in solid, liquid, or vapor states during processing. Typically, most contaminants present in soil prior to ISV processing exist in the solid or liquid state. During processing, most become either liquids or gases. The physical state of the contaminant is directly related to its mobility during ISV processing.

Movement Mechanisms:

There are five (5) basic types of mechanisms that relate to movement responses of contaminants during processing; these are detailed below.

1) Capillary action - Liquids present in soil will move from locations of thicker to thinner films, and toward regions of lower film tension. Two of the more important variables affecting capillary action during ISV are the thermal effects on the soil porosity (pore size) and the effect of heating on the viscosity of the liquid undergoing capillary action. During ISV, capillary movement is toward the dry zone and the melt. Liquids move in this direction until such time that they are vaporized.

2) Concentration-based vapor diffusion - Vaporization occurs at the vapor-point isotherm for each particular material; for most hazardous organics, that isotherm is located between the 100°C isotherm and the melt. The behavior of vapors is described by the laws of vapors and gases. Most importantly, it is known that vapors will distribute, by diffusion, within the available void volume which exists at a temperature between the vapor point isotherm and the melt temperature. Such distribution is directed toward establishing a uniform, equilibrium condition within that volume. Since vaporization occurs at the coolest boundary of this volume, and the concentration of

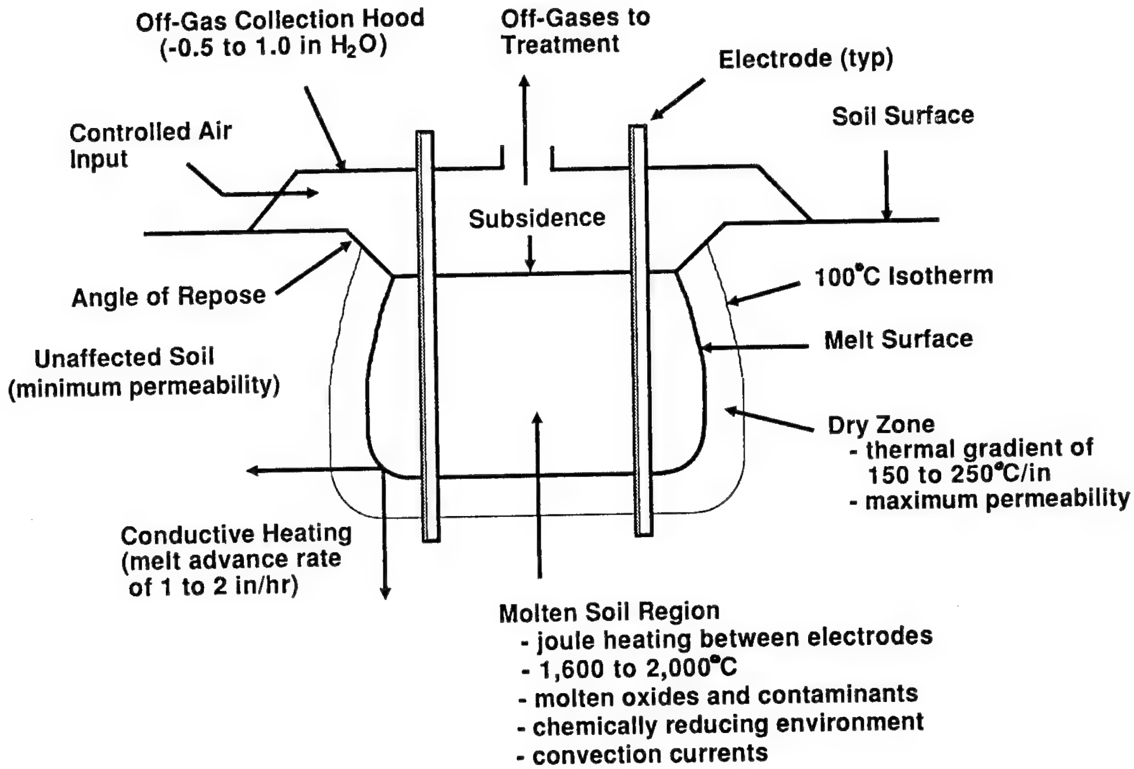


FIGURE A-1. Basic Physical Conditions of Melt and Adjacent Soil During ISV Processing

vapors is initially a maximum at that point, the concentration-based diffusion moves down the concentration gradient, towards the melt. As vapors move under equilibrium conditions, some may recondense at the vapor point isotherm; however, vapors cannot move to cooler locations beyond the vapor point isotherm without recondensing. Any removal of vapors from the vapor zone, for example due to recondensation, pyrolysis or physical removal, directly affects the equilibrium conditions, concentration gradients, and subsequent diffusion.

3) Thermally induced vapor transport - As liquids vaporize and diffuse toward the melt, there is a resulting temperature, volume, and pressure increase. Observation of ISV melts indicates that these conditions result in the vapors moving into the melt and through the dry zone adjacent to the melt. In no case have vapors been observed to move into the adjacent soil; such pathway is recognized as a path of higher flow resistance due to the soil interstitial volume being partially or fully filled with water.

Movement of vapors within the dry zone is constrained by the limited void volume present within soil; however, that volume is maximized in the dry zone, where, in addition to the absence of liquid water, there may also be cracking, channeling and some fluidization between soil particles. Movement within the dry zone may also be assisted by the negative pressure (0.5 to 1.0 inches of water) existing under the off-gas collection hood.

Water vapor is the predominant vapor present within the treatment zone during ISV processing. Water is usually present in soil in the 15 to 30 wt% range whereas hazardous contaminants are usually present at concentrations well under 1 wt%. It is known that water vapor (steam) will incorporate volatile organics that are soluble in water, and thus, contribute directly to their movement within the treatment zone. It is also recognized that a vapor may be physically swept along by the flow of water or other vapors; this combination of vapor interactions is termed carrier gas transport.

4) <u>Melt convective flow</u> - The molten mass present during ISV undergoes convective flow. This flow contributes to the heating of the overall molten mass. The flow also has the effect of uniformly distributing contaminant materials (e.g., heavy metals) present within it.

5) <u>Liquid/vapor adsorption on soil</u> - Whereas most of the mechanisms noted above contribute directly to the movement of contaminants toward the melt, the occurrence of liquid and/or vapor adsorption on soil particles tends to impede such movement. Adsorptive forces have the affect of holding some contaminants in place until thermal affects overcome the forces.

<u>Physical/Chemical Reaction:</u>

Lastly, in addition to change of state and physical movement, most contaminants may be expected to undergo physical and/or chemical reactions during ISV processing. Many organic compounds will undergo pyrolysis (thermally caused decomposition in the absence of oxygen) during processing. The pyrolysis reaction is most important for the destruction of hazardous organics. It is also possible for the compounds or their pyrolysis products to enter into chemical reaction (e.g., combination, replacement) with other materials present in the treatment volume. Figure A-2 illustrates the response categories discussed above.

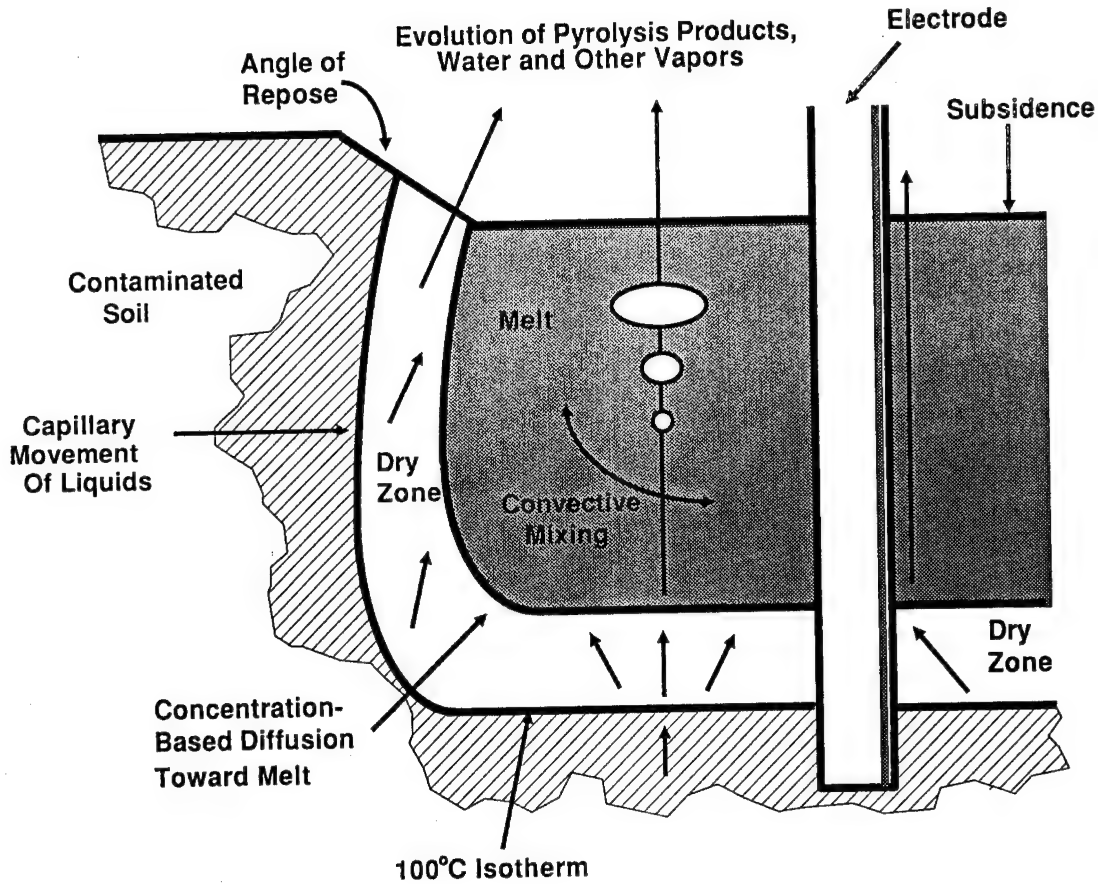


FIGURE A-2. Types of Contaminant Response to ISV Process Conditions

Ultimate Contaminant Disposition

The combination of processing conditions and responses of contaminants may result in five (5) basic dispositions of the contaminants, as detailed below.

1) Destruction of compounds - As organic vapors distribute themselves throughout the void space adjacent to the melt, they increase in temperature to their pyrolysis temperature, where they break down into successively smaller chains of molecules and eventually reach the state of elemental or diatomic gases. Upon pyrolysis, the concentration of the original compound vapor is thereby diminished, resulting in

a continued concentration gradient of the original vapor toward the pyrolysis isotherm (i.e., toward the melt). This mechanism contributes directly to the destruction of hazardous compounds during ISV.

Pyrolysis is the predominant mechanism resulting in the destruction of hazardous organics. Destruction efficiencies in the soil column on the order of 99.9 to 99.995 wt% have resulted from ISV tests involving hazardous organics. Many inorganic compounds also thermally decompose during ISV (e.g., various minerals, nitrates, sulphates). Limestone, for example, decomposes and releases carbon and oxygen during processing.

2) <u>Physical removal from the treatment volume</u> - Those vapors that are not incorporated in the melt or destroyed via pyrolysis during processing may be expected to escape the treatment volume by the movement mechanisms discussed above. Such vapors are collected and treated (i.e., removed to below air emission requirements) in the off-gas treatment system. ISV test experience has indicated that less than 0.005 to 0.1 wt% of tested organics are removed from the treatment volume, with substantially the remainder being destroyed by pyrolysis. The off-gas treatment system is capable of removing a minimum of 99.9 wt% of the organics present in the off-gas. This removed material, whether captured in the off-gas scrubber solution or in an activated carbon bed, may be recycled back to a subsequent ISV setting.

3) <u>Chemical incorporation within the vitrified residual</u> - Upon completion of ISV processing, the cooling time of the molten mass determines the relative extent of glassy phase and crystalline phase present in the residual product. Typically, the molten mass solidifies into a vitrified (silicate glass) and microcrystalline product which is physically and chemically equivilant to natural obsidian (geologic glass of volcanic origin).

The ISV silicate glass is very durable relative to environmental exposure and will hold a wide variety of materials in nonleachable form. The high solubility of heavy metals and radioactive nuclides in glass makes the ISV product unequalled for long-term immobilization of such hazardous materials. EPA tests performed on typical samples have indicated that the product is unaffected by wet/dry and freeze/thaw cycling. It has also been demonstrated capable of passing EPA's EP-Tox, SWLP, and TCLP leach testing protocols. Thus, the chemical incorporation of inorganic contaminants within the glass ISV product should be of sufficient quality to allow delisting of the vitrified mass under current EPA guidelines. EPA has also found the ISV

product to possess acceptable biotoxicity relative to near surface life forms.

4) <u>Physical encapsulation within the vitrified residual</u> - Some high melting inorganics (e.g., refractory ceramics) may become securely encapsulated by the vitrified mass rather than being melted and chemically incorporated into it. For example, it has been observed that the quartz component (melting point of 1,713°C at 1 atm) of rocks may become encapsulated during melting if sufficient time at temperature has not allowed complete melting or dissolution. Hazardous inorganics are not typically found with such refractory properties.

5) <u>Continued existence within the treatment zone</u> - Under certain conditions it may be possible for a contaminant to remain untreated or in a modified form within the treatment zone. In the case of organics, it is recognized that the mechanism of concentration-based diffusion may result in a low level of contamination in the dry zone beyond the melt since the contaminant vapors will try to maintain a uniform concentration throughout that zone even after the melt has progressed past the original contaminated zone. Such "back diffusion" is resisted by other movement mechanisms that serve to move the vapors toward the melt and/or the ground surface. ISV test experience on organics has indicated that such residual contamination is usually not detected, but when present, is miniscule compared to the amount of contaminant destroyed and removed; the amount has not been significant relative to required DRE performance on organics.

<u>Typical Contaminant Disposition</u>

Certain response types and ultimate dispositions are dominant for various classes of contaminants. Pyrolytic destruction is the dominant response (and disposition) of hazardous organic contaminants (typically 99.9 to 99.995 wt% destroyed). Together with the removal of organics from the off-gas volume, these two mechanisms provide the high degree of treatment required for hazardous organics. The level of destruction can be increased by recycling the organics recovered in the off-gas system to a subsequent ISV setting. The chemical incorporation and encapsulation dispositions are not considered possible for organics; and the possibility of continued existence as a residual is considered insignificant.

Chemical incorporation is the dominant disposition of most hazardous inorganic elements (e.g., heavy metals). The quality of this incorporation is sufficient to qualify as permanent immobilization for such hazardous contaminants (a delistable product). Some amount of volatile or semivolatile inorganics

(e.g., Pb, Hg) may be removed from the treatment volume and be recovered in the off-gas treatment system; they may then be disposed by an alternative means or be recycled to a subsequent ISV melt for further disposition by chemical incorporation. Pyrolytic destruction of hazardous inorganic compounds (e.g., CN) is possible; however, destruction of hazardous elements (e.g., heavy metals) is not possible. The alternative dispositions of encapsulation and continuation as a residual are not considered to be significant for hazardous inorganics.

APPENDIX B

DISCUSSION OF POSSIBLE WASTE ARRANGEMENTS FOR ISV PROCESSING

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DISCUSSION OF POSSIBLE WASTE ARRANGEMENTS FOR ISV PROCESSING

Waste materials may be arranged in a variety of ways for ISV processing. Eight basic processing arrangements are discussed and illustrated below; combinations of the arrangements may also be possible under certain site conditions.

Figure B-1 illustrates the classical in situ (in the original place) application. Such application arrangements are applicable to landfill or general soil contamination conditions where the contaminants are deep enough (rule of thumb: >5 to 7 ft) to allow economic application of ISV. In situ applications enjoy the advantage of greater safety since the excavation of hazardous materials can be avoided.

Figure B-2 illustrates how the ISV process may be applied in situ to contaminated soils under and around a surface impoundment. In such cases it is common to level the impoundment either by removing the berm, by filling the depression volume with soil, or by a combination of the two (e.g., placing part of the berm within the impoundment). The presence of liners (e.g., plastic) under an impoundment may also be accommodated by the ISV process.

Figures B-3 and B-4 illustrate two variations of waste material staging arrangements. Figure B-3 represents the case where a trench may be provided for staging of the contaminated materials completely below grade. Figure B-4 illustrates how materials may be staged totally or partially above grade if desired. The placement of clean soil above the contaminated materials in both these cases is an option depending on whether it is desirable to minimize the volatilization of contaminants at the surface during process startup.

Staging of contaminated materials should be considered when: 1) the contamination is very shallow (e.g., <5 to 7 ft), 2) the contamination cannot be processed where it presently is located, 3) it is considered necessary to add soil to or above the contaminated material, and/or 4) it is desired to minimize the area of treatment by consolidation. It should be noted that this third option, addition of soil to waste materials, allows for the ISV processing of containerized materials that were not originally present within soil.

Figure B-5 illustrates a special variation of the staging concept as it may apply to remediation of contaminated tanks or containers. In this case the tank or other container is filled with

soil prior to vitrification of the complete volume. Metal tank materials would be expected to melt and become part of the residual product during treatment. Non-metal tanks would be destroyed by the processing.

Figure B-6 illustrates the special case of ISV treatment to depths greater than are possible in a single ISV setting. For deep applications (e.g., >30-ft) the special case of stacked settings, as illustrated in Figure 8, is an option. In the case of stacked settings, a deep setting is performed first, followed by placement of additional material atop the first monolith for subsequent processing. If stacked settings were to be performed on in situ soils, it would be necessary to first excavate the upper material to allow vitrification of the lower setting; this would not be the case if the stacked settings were performed on staged contaminated material.

Figure B-7 illustrates a variation of the stacked setting concept for the special case of staged, high-volume reduction materials (e.g., sludge or tailings undergoing a significant percentage of conversion to gaseous products during processing). In this case a process container may be utilized, above, at, or below grade, to hold the staged material. After completing the first setting, the container would be refilled for a second setting. Such would be repeated until the container was as full of residual product as desired.

Lastly, Figure B-8 illustrates a continuous feeding arrangement wherein contaminated materials would be fed between the electrodes, allowing a period of continuous processing. Such an arrangement may be another possibility for cases of high volume reduction materials.

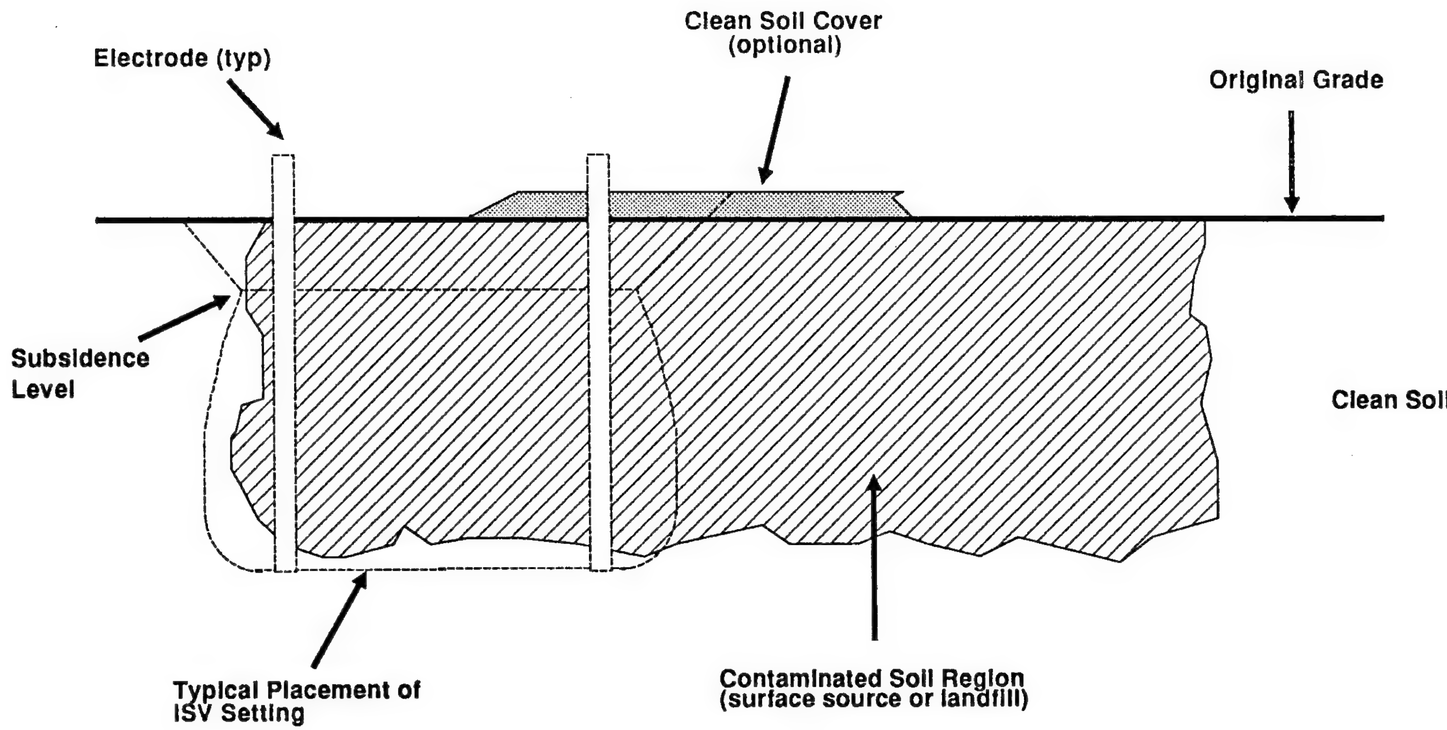

FIGURE B-1. In Situ Processing Arrangement

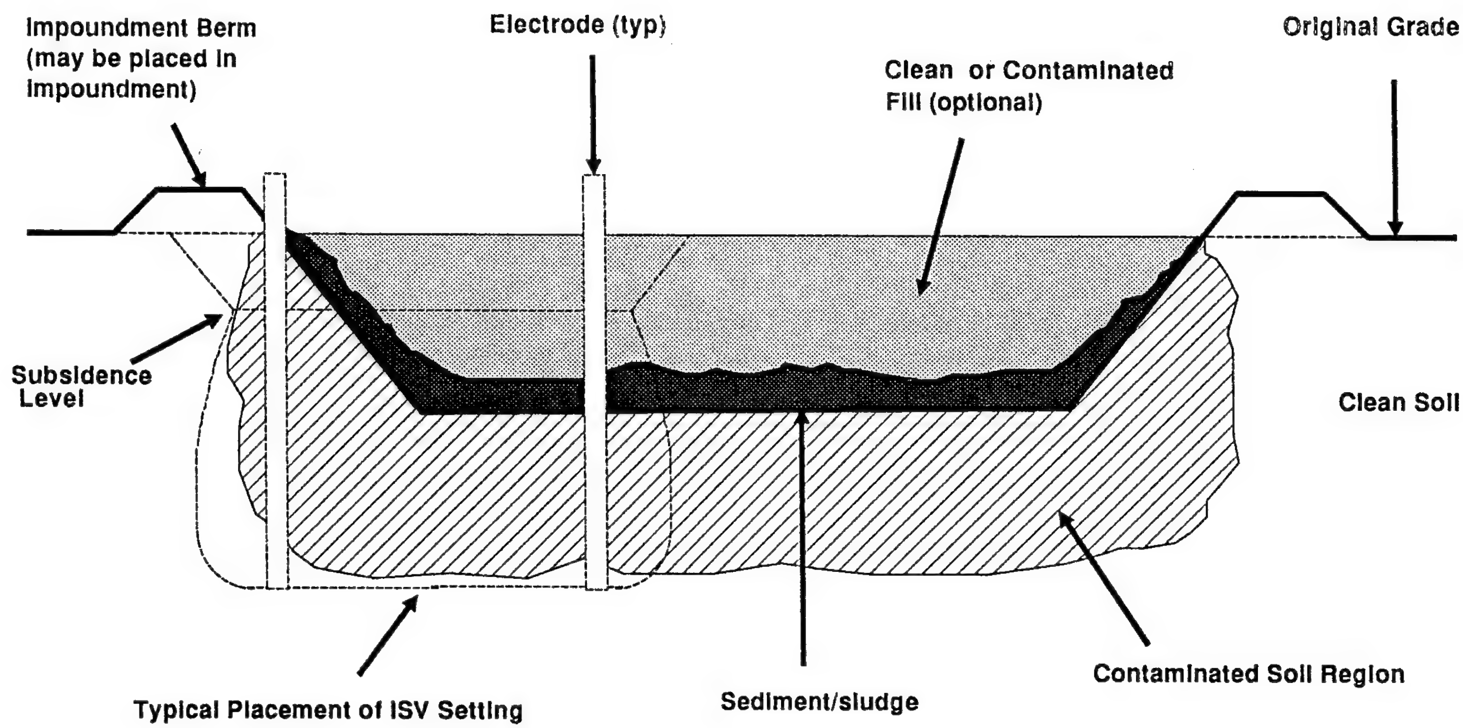

FIGURE B-2. Modified In Situ Processing Arrangement

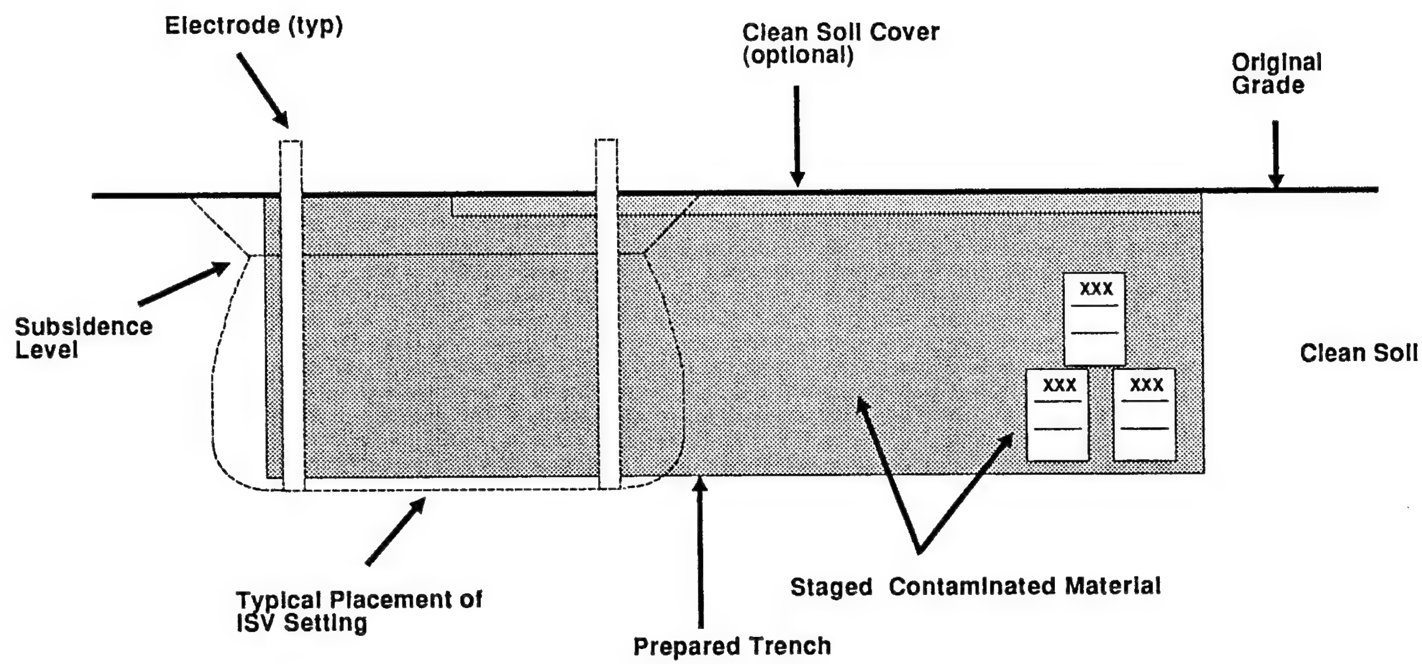

FIGURE B-3. Below-Grade Staging Arrangement

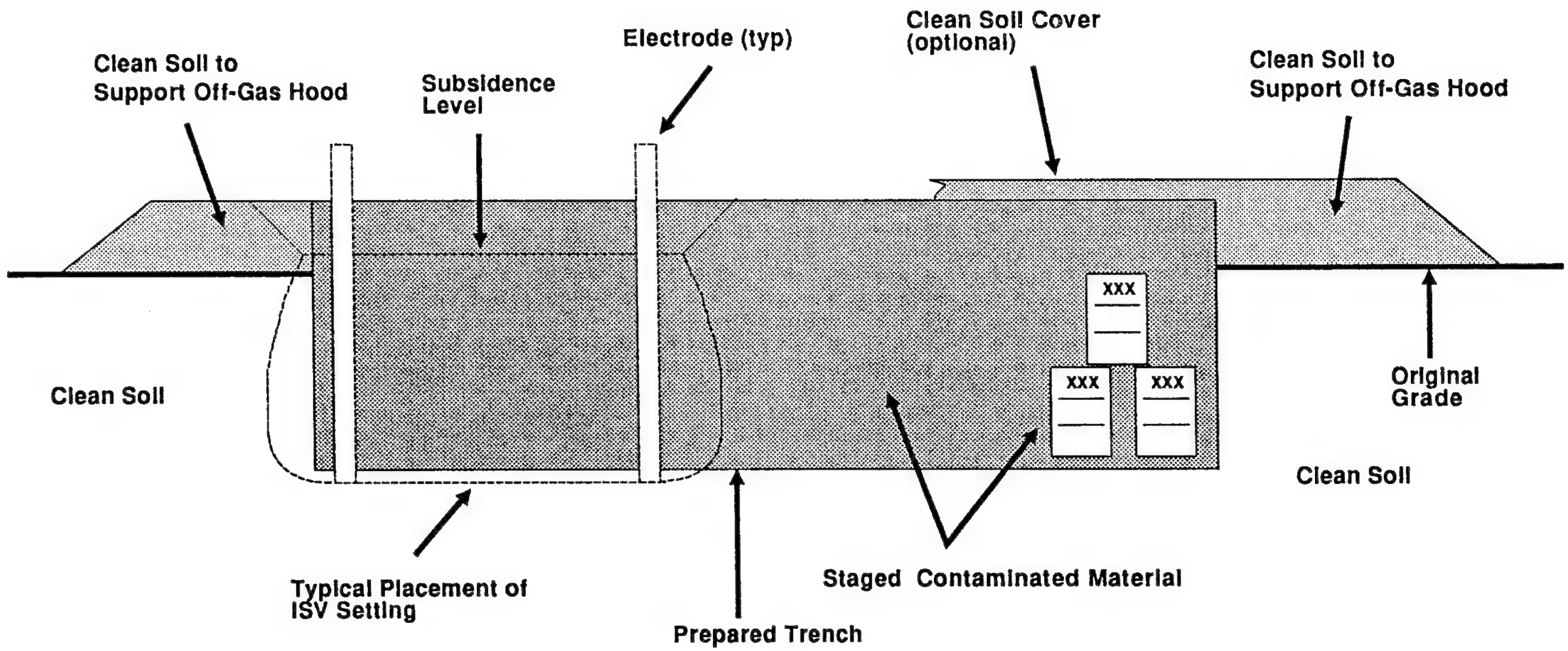

FIGURE B-4. Above-Grade Staging Arrangement

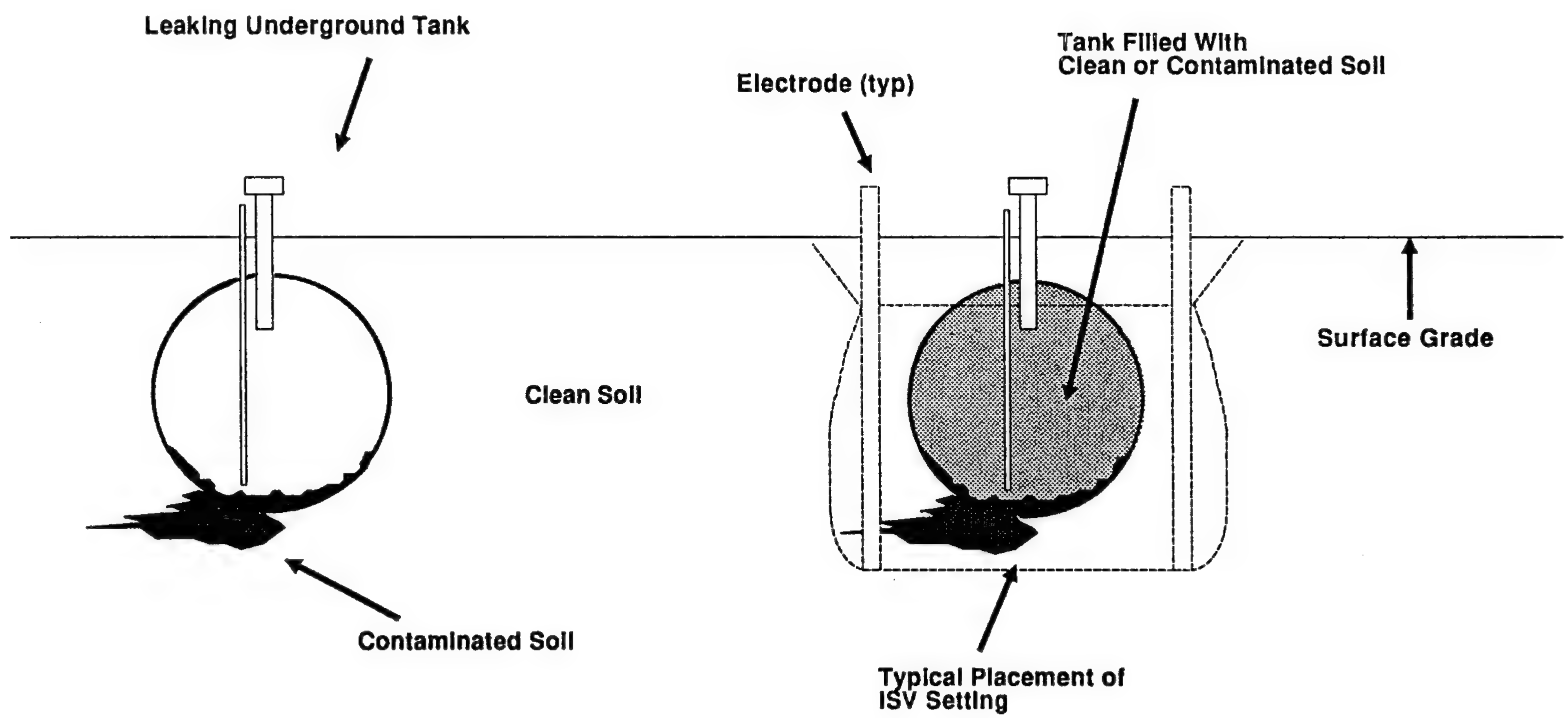

FIGURE B-5. Tank/Container Setting Arrangement

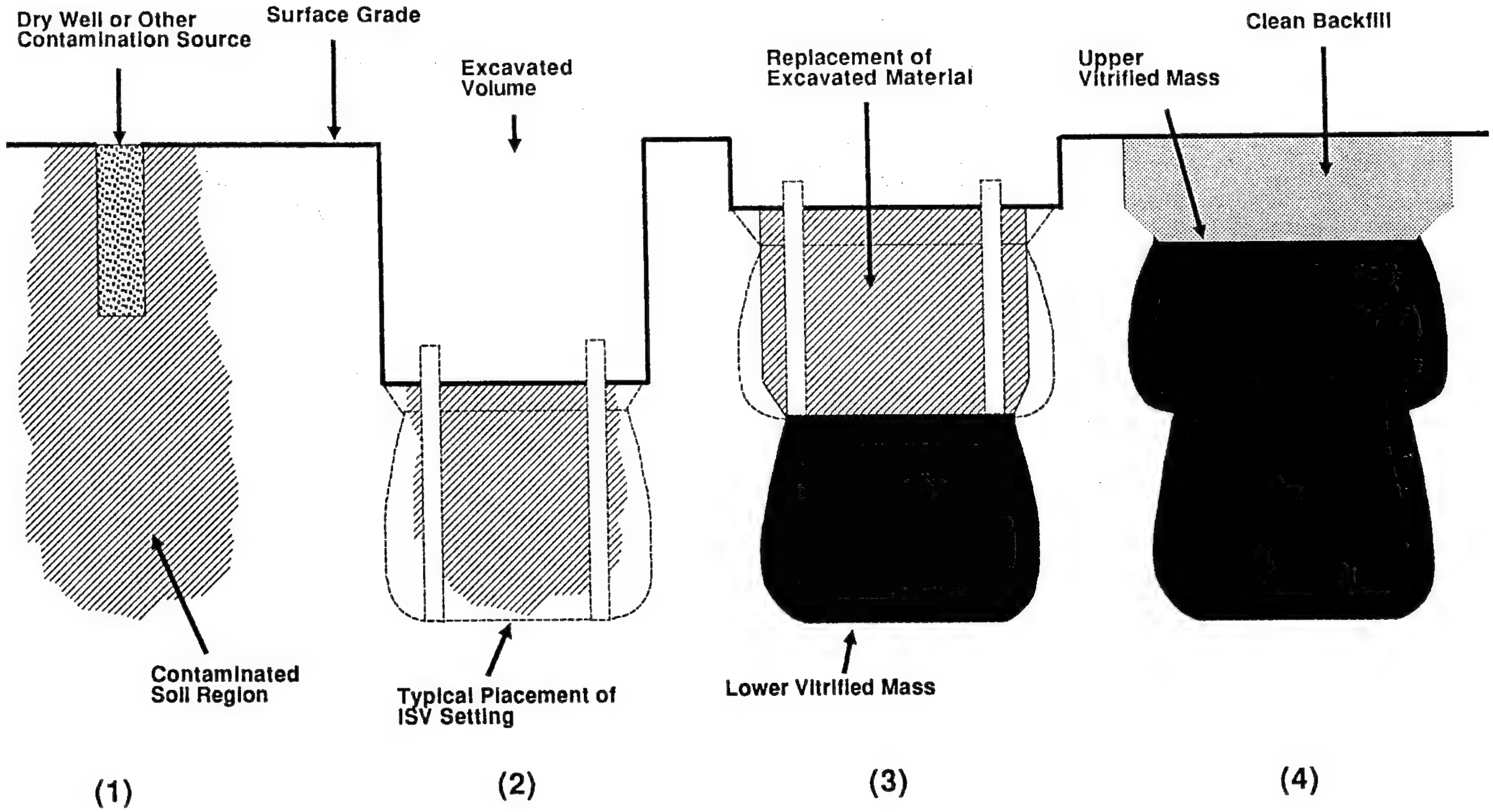

FIGURE B-6. Stacked Setting Processing Arrangement

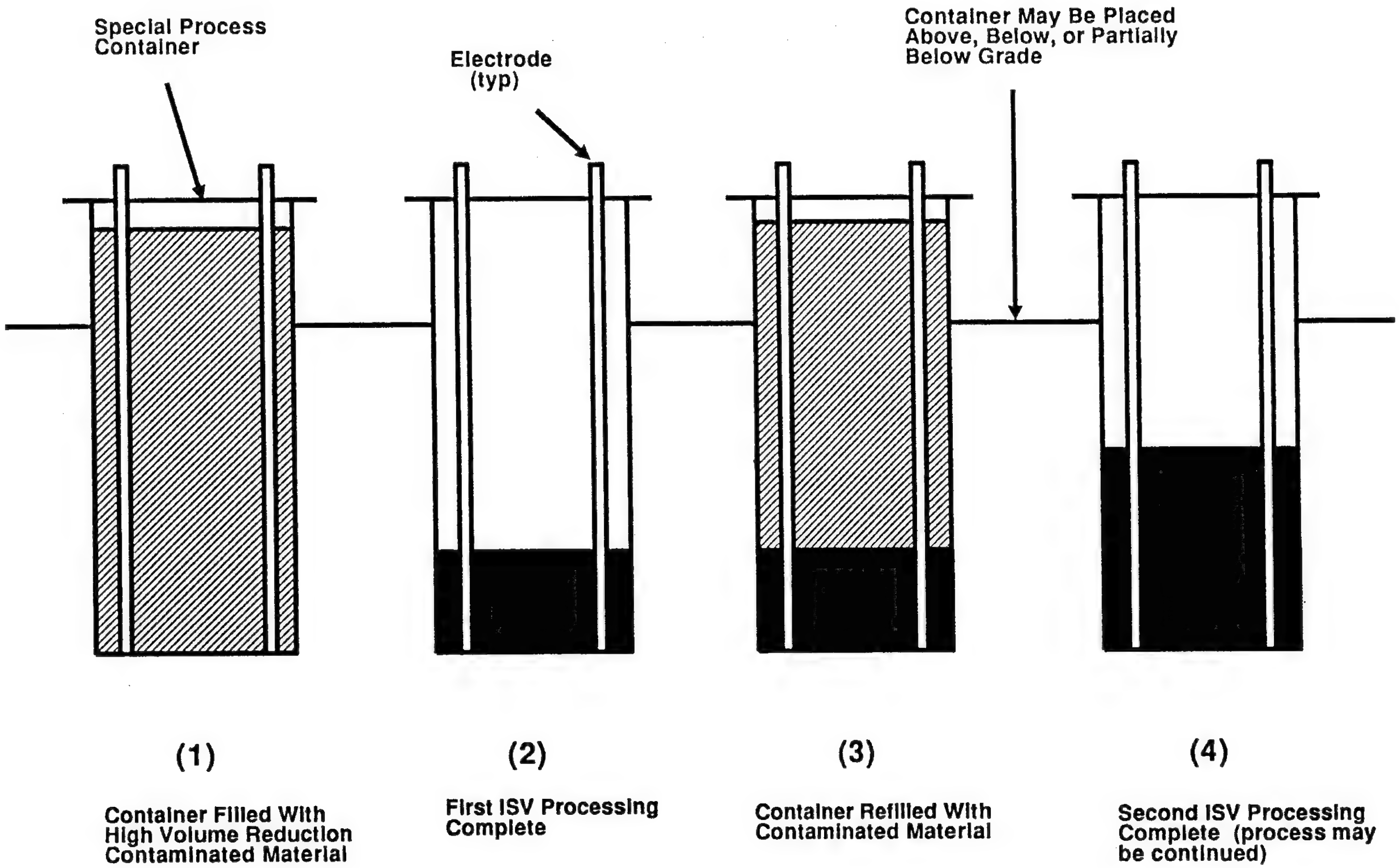

FIGURE B-7. Process-Container Repetitive Setting Arrangement

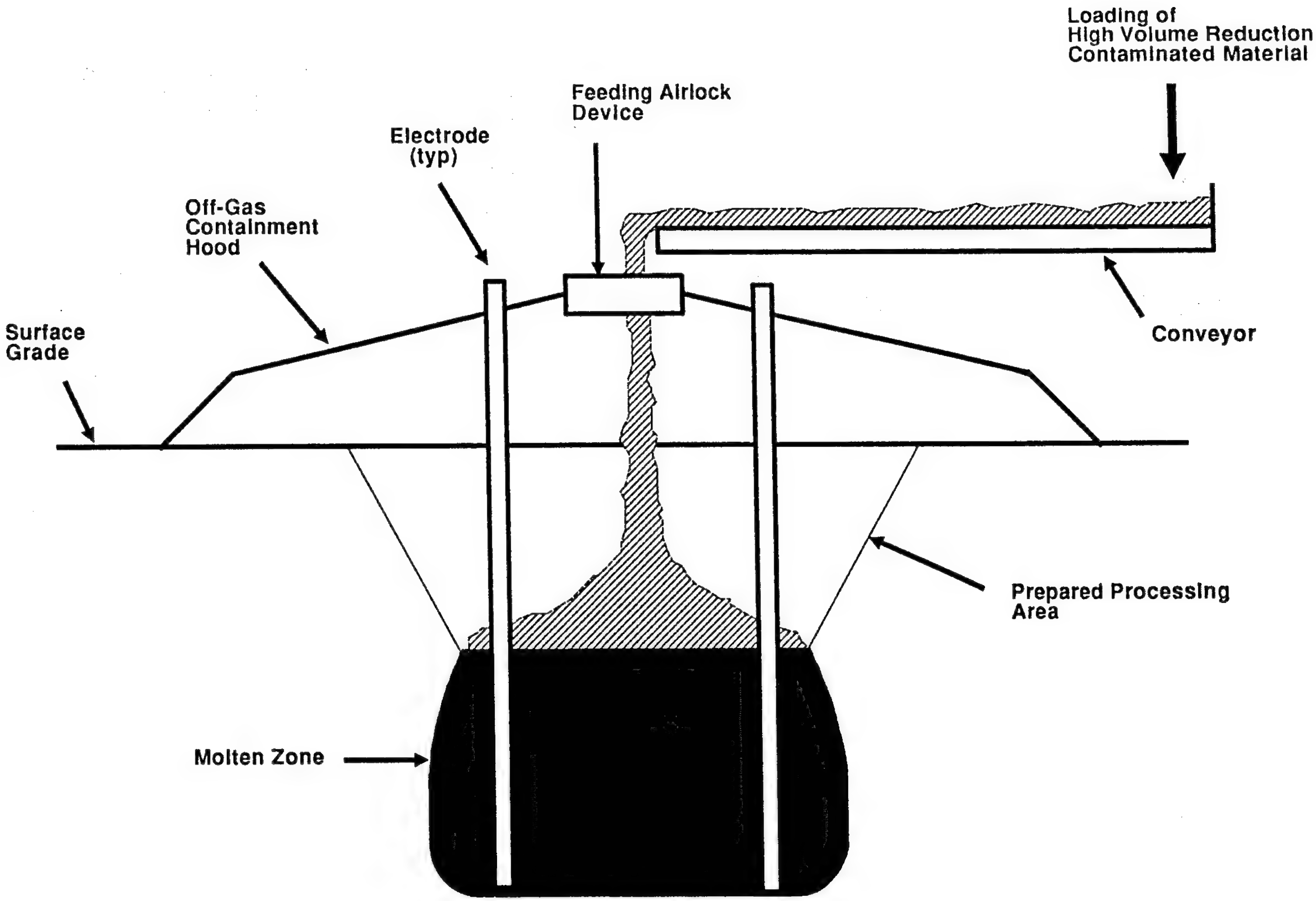

FIGURE B-8. Continuous Feed Processing Arrangement

APPENDIX C

INFORMATION NEEDED FOR DEVELOPMENT OF ISV COST ESTIMATE

APPENDIX C

INFORMATION NEEDED FOR DEVELOPMENT OF ISV COST ESTIMATE

1. Contaminant chemical composition, and concentration (max and average) versus soil depth profile
2. Required cleanup levels, by contaminant
3. Exothermic heat value of organic mixtures
4. Soil stratigraphy, permeability, and bulk density; and chemical and oxide composition, fusion temperature, and density of major constituents
5. Soil moisture content (typical range)
6. Depth of groundwater and recharge rate (if waste is in or near water table)
7. Presence of rubble, void volumes, and other inclusions in volume to be treated
8. Volume (depth and area) to be treated
9. Local price ($/kwH) for electricity (large industrial usage)
10. Distance from 12,500 or 13,800 volt power source capable of 4 megawatt supply
11. Site topography
12. Site distance from public residences
13. Presence of structures and/or underground utilities near treatment area
14. Responsible parties
15. Regulatory classification and ARARs
16. Site name, location (State), and responsible regulators.

APPENDIX D

QUALITATIVE COMPARISON OF ISV TO LANDFILL, CHEMICAL STABILIZATION, AND INCINERATION TECHNOLOGIES

COMPARISON OF ISV TO LANDFILL (Soil and Sludge Applications)

Remediation Criteria	ISV	Landfill
1. Permanence/estimated life of remediation	Very permanent/geologic time period	Temporary/5-30 years (100% chance of eventual leakage)
2. Reduction of toxicity	Organics destroyed beyond EPA DRE requirements	None
3. Reduction of mobility	Inorganics permanently "immobilized" in delistable residual	Reduction achieved through monitored, retrievable storage
4. Reduction of contaminated volume	25%-30% reduction minimum for most soils, greater reduction possible for sludges	None, slight (10-20%) increase
5. Performance on-site	Yes - mobile, on-site	Typically off-site, can be constructed on-site
6. Performance in-situ	Yes, with or without staging	Possible
7. Reduction of long-term liability	Maximum possible benefit	None
8. Cost effectiveness	High cost, commensurate with performance	Typically lower than ISV if transport distance is minimal and no radioactivity is present. Rapidly increasing costs due to land disposal restrictions.
9. Other operations required	Excavation and staging optional	Excavation, transport, stabilization (optional), redisposal, perpetual monitoring and maintenance
10. Safety	Lowest possible occupational exposure, zero transport risk, inherent in-situ safety benefits	Maximum occupational and transport exposure risk
11. Public acceptance	Very good	Poor

COMPARISON OF ISV TO CHEMICAL STABILIZATION (Soil and Sludge Applications)

Remediation Criteria	ISV	Chemical Stabilization
1. Permanence/estimated life of remediation	Very permanent/geologic time period	Temporary/5-100 years
2. Reduction of toxicity	Organics destroyed beyond EPA DRE requirements	None
3. Reduction of mobility	Inorganics permanently "immobilized" in delistable residual	Good for inorganics, poor for organics
4. Reduction of contaminated volume	25%-30% reduction minimum for most soils, greater reduction possible for sludges	Volume increase due to addition of stabilizing materials (10-40%)
5. Performance on-site	Yes - mobile, on-site	Not typical; future possibility
6. Performance in-situ	Yes, with or without staging	Yes, possible
7. Reduction of long-term liability	Maximum possible benefit	Temporary stay of liability
8. Cost effectiveness	High cost, commensurate with performance	Lower cost indicative of performance
9. Other operations required	Excavation and staging optional	Excavation, pretreatment, placement, capping, monitoring
10. Safety	Lowest possible occupational exposure, zero transport risk, inherent in-situ safety benefits	High occupational exposure risk, zero transport risk
11. Public acceptance	Very good	Poor

COMPARISON OF ISV TO INCINERATION (Soil and Sludge Applications)

Remediation Criteria	ISV	Incineration
1. Permanence/estimated life of remediation	Very permanent/geologic time period	Permanent for organics, not applicable to inorganics
2. Reduction of toxicity	Organics destroyed beyond EPA DRE requirements	Organics destroyed beyond DRE requirements
3. Reduction of mobility	Inorganics permanently "immobilized" in delistable residual	None for inorganics
4. Reduction of contaminated volume	25%-30% reduction minimum for most soils, greater reduction possible for sludges	Very small, to extent of organic volume (e.g., 1-5%)
5. Performance on-site	Yes - mobile, on-site	Yes, mobile, on-site
6. Performance in-situ	Yes, with or without staging	No, not possible
7. Reduction of long-term liability	Maximum possible benefit	Good for organics, not applicable for inorganics
8. Cost effectiveness	High cost, commensurate with performance	High cost indicative of organic performance
9. Other operations required	Excavation and staging optional	Excavation, pretreatment, final disposal of ash, treatment of large volumes of combustion gases, complex interrelated components, high probability of frequent downtime
10. Safety	Lowest possible occupational exposure, zero transport risk, inherent in-situ safety benefits	Higher occupational exposure risk, zero transport risk
11. Public acceptance	Very good	Poor image

APPENDIX E

DISCUSSION OF ISV AS A CONTAINMENT TECHNOLOGY

APPENDIX E

DISCUSSION OF ISV AS A CONTAINMENT TECHNOLOGY

ISV technology may be used as a containment technology for the in situ containment of hazardous wastes within contaminated soil. For purposes of this discussion, containment refers to the protected in situ storage of wastes that are present within the ground. For example, ISV may be utilized to produce barrier walls surrounding a waste impoundment (see Figure E-1). It may also be used to produce an impermeable layer (cap) over contaminated soils (see Figure E-2). It may also be used at the up-gradient side of an impoundment to produce a hydraulic depression (see Figure E-3).

The applicability of ISV for such uses is based on the properties of the residual monolith produced. The ISV residual is impermeable, very strong (10 times the compressive and tensile strength of unreinforced concrete), and essentially nondegradable. The ISV product will fuse (like a weld) to certain types of rock (e.g., basalt) producing an impermeable interface.

Formation of an ISV barrier wall is performed in a manner very similar to direct treatment applications of ISV. One major difference is that only two electrodes are used for barrier wall applications. The barrier wall produced is thicker at its bottom than at the top. Minimum thicknesses of 3 ft are typical for walls at least 10 ft deep. Wall thickness depends on the specific materials being processed. Depths up to 50 ft are considered possible.

ISV barrier walls may be produced at widths up to 30 ft per individual process setting. For long walls (e.g., hundreds of feet), it is desirable to produce the wall in intermittent sections with some sections left out until after the vitrified sections have cooled. Then the omitted sections are completed to finalize the wall. This production approach minimizes the occurrence of thermal shrinkage cracks.

Barrier wall applications also differ from hazardous waste treatment applications in that, if the walls are produced in clean soil, there may be no need for off-gas collection and treatment. Again this depends on the specific soil involved. Many soils may be processed without creating particulate and other emissions (e.g., SO_x) in excess of regulatory levels.

The use of pre-placed fluxing materials may also be used during ISV to lower the melting point of the wall materials to be vitrified. Fluxing materials may be used to minimize growth of wall thickness at deeper levels. The use of fluxing materials will impact the physical and chemical properties of residual

wall; thus their use must be considered carefully during application design.

The life expectancy of the ISV residual product is outstanding. As noted in the body of this document, the glass and crystalline product may be considered non-degradable relative to environmental and hazardous waste exposure. For barrier wall applications the structural integrity of the wall must also be considered. While the ISV product has excellent physical properties, it is possible that geologic forces (e.g., earthquake) could cause cracks or fractures in the wall. The conchoidal fracture mechanism typical of the ISV product would minimize the extent of any such damage, and it should be possible to reprocess (remelt) any damaged sections if desired.

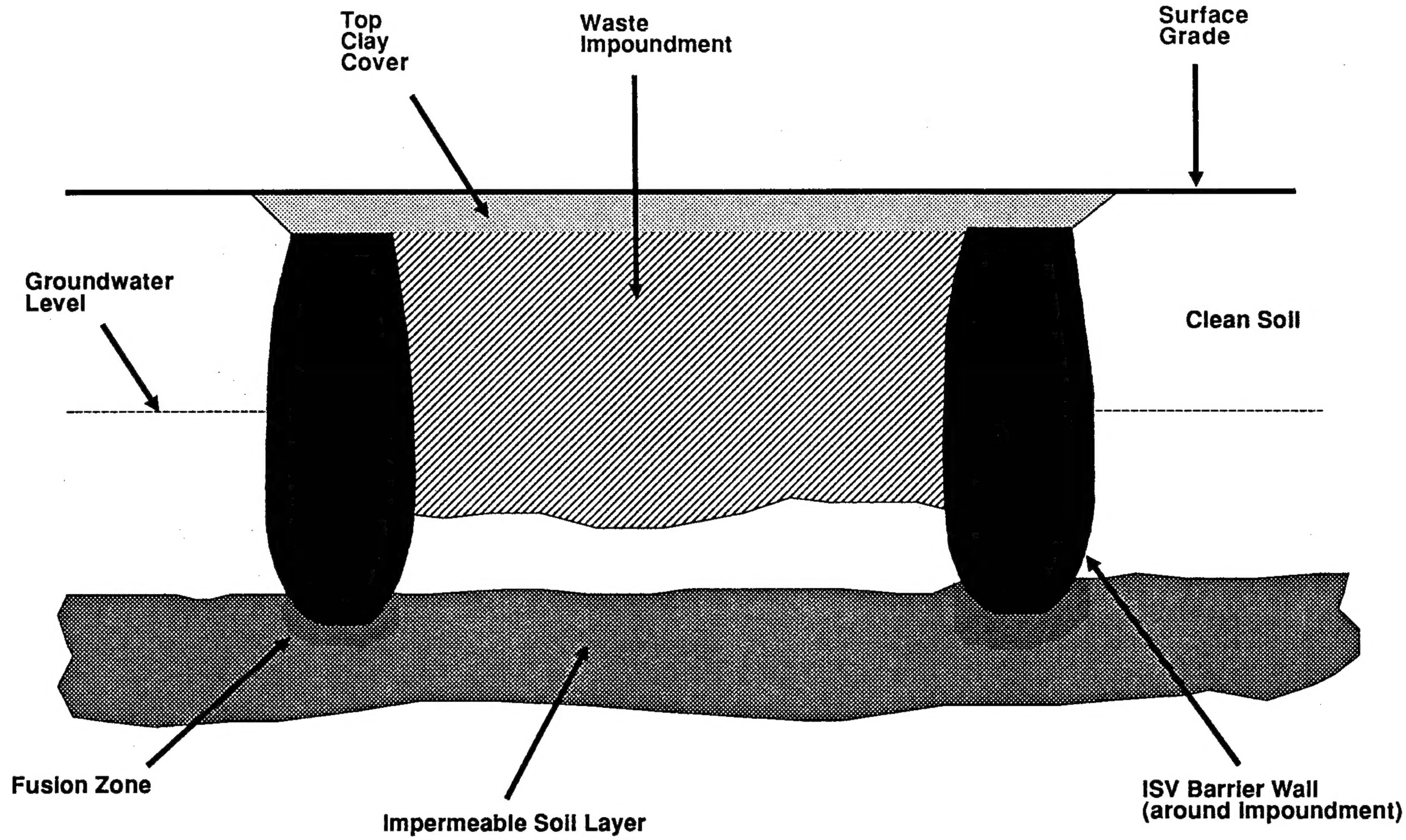

FIGURE E-1. ISV Barrier Wall Around a Waste Impoundment

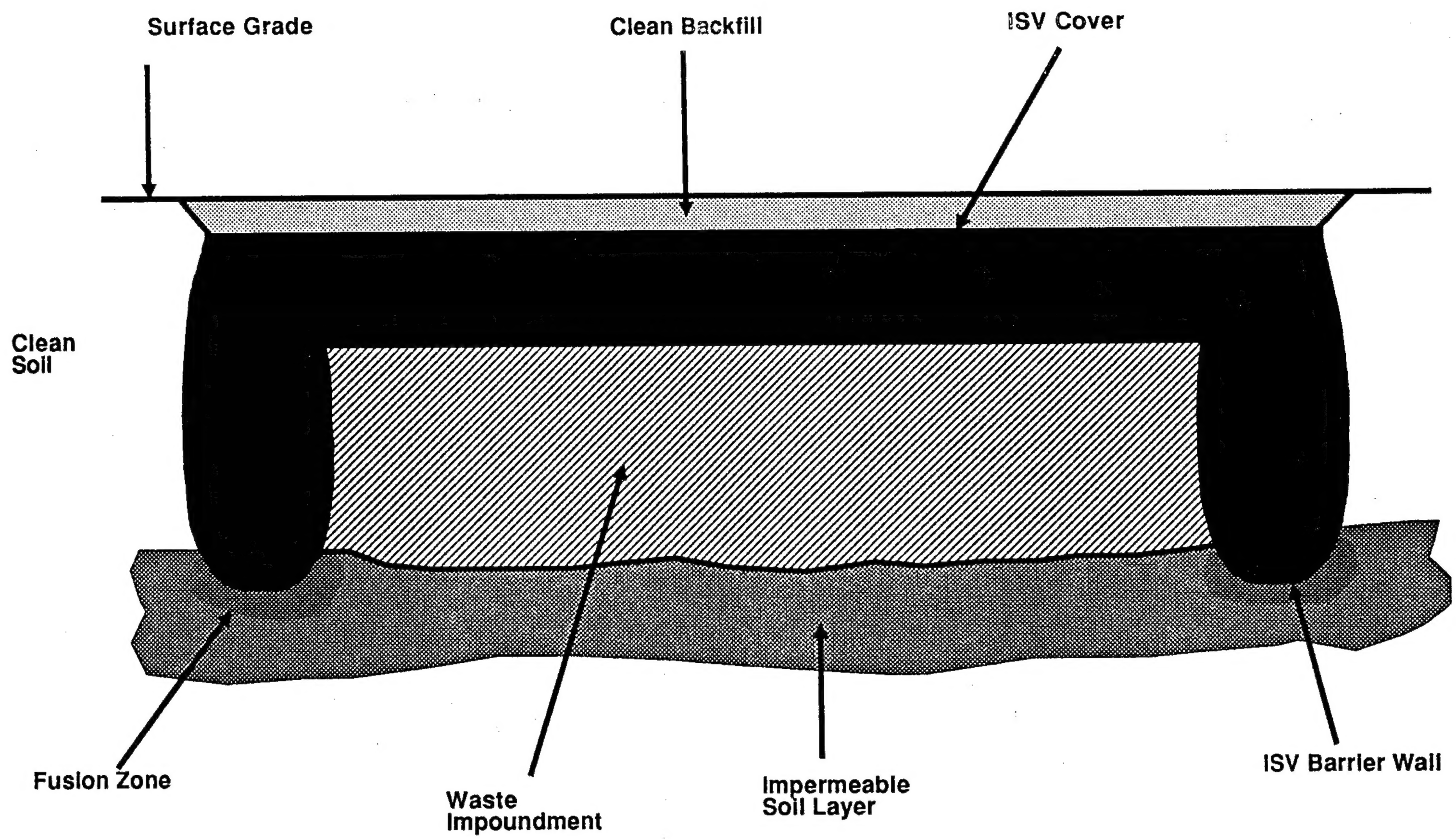

FIGURE E-2. ISV Containment Above Hazardous Wastes

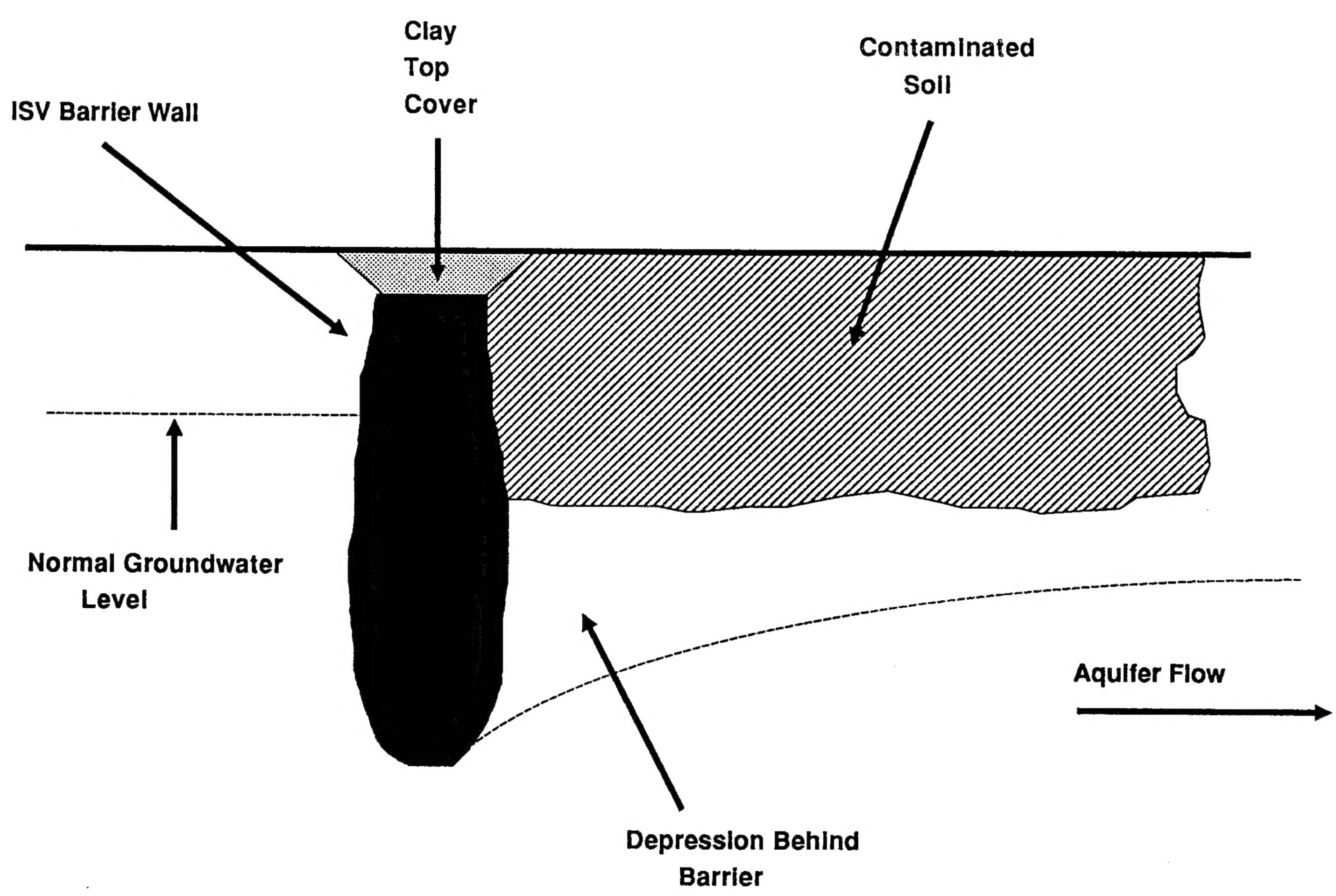

FIGURE E-3. ISV Barrier Wall Used to Produce Hydraulic Depression